PB81-183501

Cost Estimations for Emission Control Related Components/Systems and Cost Methodology Description Heavy Duty Trucks

Rath and Strong, Inc.
Lexington, MA

Prepared for

Environmental Protection Agency
Ann Arbor, MI

Dec 77

U.S. Department of Commerce
National Technical Information Service
NTIS

United States
Environmental Protection
Agency

Office of Mobile Source Air Pollution Control
Emission Control Technology Division
2565 Plymouth Road
Ann Arbor, MI 48105

EPA-460/3-80-001
February 1980

PB81-183501

Air

EPA

Cost Estimations for Emission Control Related Components/Systems and Cost Methodology Description Heavy Duty Trucks

PRODUCT OF:
NATIONAL TECHNICAL
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U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO.
EPA 460/3-78-002

2.

3. RECIPIENT'S ACCESSION NO.
PB81 183501

4. TITLE AND SUBTITLE
Cost Estimations for
Emission Control Related Components/Systems
and Cost Methodology Description

5. REPORT DATE
December 1977

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)
LeRoy H. Lindgren

8. PERFORMING ORGANIZATION REPORT NO
Contract #PO-702-3848
RFP #WA-77-B271

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Rath & Strong, Inc.
21 Worthen Road
Lexington, Massachusetts 02173

10. PROGRAM ELEMENT NO.

11. CONTRACT/GRANT NO.
Modification No. 3
Contract No. 68-03-3505

12. SPONSORING AGENCY NAME AND ADDRESS
Environmental Protection Agency
Mobile Source Air Pollution Control
2565 Plymouth Road
Ann Arbor, MI 48105

13. TYPE OF REPORT AND PERIOD COVERED
Final (July 1977-Nov. 1977)

14. SPONSORING AGENCY CODE

Reproduced from
best available copy.

15. SUPPLEMENTARY NOTES

Rath & Strong, Inc., subcontractor to Mechanical Technology, Inc.

16. ABSTRACT

This report presents estimates of the retail price equivalent (RPE) or "sticker price" for a variety of automotive exhaust emission control related components/systems. The author began with a three-level assumption as to industry makeup (supplier, vehicle assembly, dealer) and used this standard approach along with assumptions as to production volume and the amounts of labor, overhead, tooling, administrative, and depreciation expenses and profit at the supplier level, tooling, research and development, and administrative expenses and profit at the vehicle assembly level, and labor, overhead, and profit at the dealer level to determine the RPE. Where little physical description of a component could be found, a "best guess" effort was made. A methodology description is also included. It should be noted that since a specific production volume was assumed in each case, the RPE estimates are valid only within some relevant range of production volumes.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Air Pollution	Manufacturing Costs		
Exhaust Systems	Tooling		
Cost Estimates	Methodology		
Labor Estimates			
Material Estimates			
Catalytic Converters			
Air Injection			

18. DISTRIBUTION STATEMENT Release Unlimited	19. SECURITY CLASS *(This Report)*	21. NO. OF PAGES
	20. SECURITY CLASS *(This page)*	22. PRICE

EPA Form 2220-1 (9-73)

EPA-460/3-80-001

COST ESTIMATIONS FOR EMISSION CONTROL RELATED COMPONENTS/SYSTEMS AND COST METHODOLOGY DESCRIPTION HEAVY DUTY TRUCKS

by

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Order No. A-2002-NASX

EPA Project Officer: Susan Vintilla

Prepared for

ENVIRONMENTAL PROTECTION AGENCY
Office of Air, Noise and Radiation
Office of Mobile Source Air Pollution Control
Emission Control Technology Division
Ann Arbor, Michigan 48105

February 1980

i.a

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Publication No. EPA-460/3-80-001

PREFACE

This report consists of the development of a manufacturing cost data base of a group of emission systems and components as specified by the Environmental Protection Agency. The cost methodology is included for each system. The dollar amounts presented in this report are in terms of 1977 dollars.

Scope of Work

A. The contractor shall provide all of the necessary facilities, equipment, personnel, analysis, and reporting required to complete the following tasks in an efficient and effective manner.

B. Task 1 - Cost of Components/Systems

1. The contractor shall provide cost estimates for the emission control or emission control related components/systems listed in Attachment A for 4, 6, and 8-cylinder engines with further cost breakdowns of these components/systems where indicated on the attachment. These individual costs shall include but not be limited to the following: a) material costs; b) labor costs; c) overhead costs, including indirect labor, supplies, electricity, heating, plant and equipment repairs, supervision, plant and equipment depreciation, insurance; and d) appropriate markup rates or factors.

2. These costs shall reflect economies of scale, current material, labor, and overhead costs, appropriate manufacturing processes, and shall be ranged to reflect a 3-year or a 12-year writeoff of investment.

3. The Project Officer must approve the choice of production volume used in calculating the effect due to economy of scale.

C. Task 2 - Description of Methodology

1. The contractor shall provide a detailed description of the methodology used to determine the estimates in Task 1 above. Where possible, more than one method shall be used to increase the assurance of the estimates' accuracy.

Acknowledgements

This report has been generated from engineering data available at this writing. Some of the data is based on industrial engineering judgment. The cost data is based on the best possible industrial engineering estimating procedures using product knowledge, manufacturing experience, and learning curve techniques. Whenever possible other estimating work was used for comparative purposes. Also, the aftermarket selling price data was used to establish a frame of reference or an order of magnitude cost computation using known discount data.

The author would like to acknowledge the cooperation of EPA personnel Mr. Karl Hellman and Ms. Susan Vintilla. Mr. W. Leitch and Ms. S. Zemann of Rath & Strong were major contributors to this report. The production office of Rath & Strong typed and edited the final report to a level of detail beyond the original plan of work.

Attachment A

Components/Systems to be Cost-Estimated

1. PCV valve
2. TCS (thermal control switch)
3. OSAC (orifice spark advance control)
4. Deceleration valve
5. Anti-dieseling solenoid
6. Air injection system (breakdown by: pump, dump, lines, exh. man. mods.)
7. Air switching system (breakdown by: approx. 3 foot of tubing, 2-way valve)
8. Reed valve air system
9. EGR system (types: sonic-electronic with and without cooler, sonic-pneumatic with and without cooler, back-pressure modulated, venturi vac amplified)
10. Pelleted oxidation catalyst (as a function of volume, noble metal loading, and composition)
11. Monolithic oxidation catalyst (as a function of volume, noble metal loading, and composition)
12. Pelleted reduction catalyst (as a function of volume, noble metal loading, and composition)
13. Monolithic reduction catalyst (as a function of volume, noble metal loading, and composition)
14. Monolithic start catalyst (as a function of volume, noble metal loading, and composition)
15. Monolithic 3-way catalyst (as a function of volume, noble metal loading, and composition)
16. Metallic reduction catalyst (as a function of volume, noble metal loading, and composition)
17. Oxygen sensor (as a function of Pt loading)
18. Electronic fuel metering system (breakdown by: actuators, regulator, filters, tubing, pump, nozzles (# of cylinders plus one), vol air flow sensor (L-Jetronic and K-Jetronic type), mass air flow sensor (Chrysler type)

19. Thermal reactor (types: insulated with core, insulated without core)

20. Exhaust manifold (stock)

21. Port liners (types: cast in, inserted air-gap with and without locater ribs)

22. Radiator (types: stock, with 20% weight reduction)

23. Quick heat manifold (breakdown by: EFE valve with vacuum motor actuation and with 25 in^2 wavy steel heat transfer surface replacing 25 in^2 of cast iron)

24. Super early fuel evaporation (breakdown by: 2 valves, heat transfer surface, tubing)

25. Electric heated choke

26. High energy ignition

27. Breaker point ignition (breakdown by: centrifugal advance system, vacuum advance system)

28. Improved exhaust system (cost per foot of stainless steel from exhaust manifold to catalyst)

29. Standard steel exhaust system (cost per foot of low carbon steel from exhaust manifold to approximate catalyst location)

30. Insulated exhaust pipe (cost per foot of double wall stainless steel)

31. Carburetor modifications for altitude compensation (breakdown by: aneroid, linkage)

32. Carburetor modifications for feedback control unit (1, 2, 4 barrels)

33. Standard Carb (1, 2, 4 barrels)

34. Electronic control unit (with sensor inputs for controlling modulated AIR, modulated EGR, modulated A/F, modulated spark advance)

35. Air modulation system (with vacuum control)

36. Spark knock sensor (with piezo-electric accelerometer or pickup)

37. Transducers + Sensors (types: H_2O temperature, inlet air temperature, throttle-position, engine speed, engine load, fuel flow, transmission gear, EGR pintol position, crank angle, humidity)

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HEAVY DUTY DIESEL ENGINES

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APPENDIX - METHODOLOGY COST DERIVATION

Introduction

In its regulation of the heavy duty truck industry, the U. S. Environmental Protection Agency is frequently confronted with the issue of cost to the consumer of systems installed on automobiles for the purpose of controlling emissions. Ideally, it would be desirable to determine the economic impact on the consumer for any emission standard proposed and on any vehicle for which such a standard would be applicable. Since such a task would involve a very high level of effort, a more realistic goal would be to determine an aggregate cost estimate representative of the cost of all components or systems of a similar nature, for example, EGR valves or EGR systems. This would necessarily imply that many individual components or systems could be expected to cost more or less than the aggregate or weighted average cost estimate.

In most situations a full cost, as opposed to a differential cost approach is more appropriate for determining the true cost of producing a particular component. This means that all components comprised by a truck must reflect a share of fixed overhead and corporate level costs such as salaries, maintenance, insurance, heat, power, lighting, and so on. This approach is consistent with changes made to a vehicle which are expected to be of a relatively long-term nature whereas the differential cost approach of merely reflecting the addition of direct material, direct labor, and variable overhead costs due to an added component is adequate only for relatively short-term purposes.

Taking into account all of the variations in industry makeup which exist in the real world would present a very complex problem. For example, the number of suppliers supplying a corporation with a given component varies not only among the different components on a given vehicle but among the different vehicle manufacturers as well. Some suppliers are in turn supplied by other suppliers. Some suppliers supply components to more than one manufacturer. These variations influence production volume which in turn influences the economies of scale attainable by a manufacturer.

To make the problem more manageable, assumptions have been made which help simplify the cost estimate task. Figure 1, below, depicts the industrial makeup assumed in this study.

Judicious choice of production volumes helps minimize cost differences due to the reliance upon more than one supplier. (Truck manufacturers are sometimes supplied a given component by more than one supplier as a precaution against labor strikes or other occurrences which might interrupt that supply.)

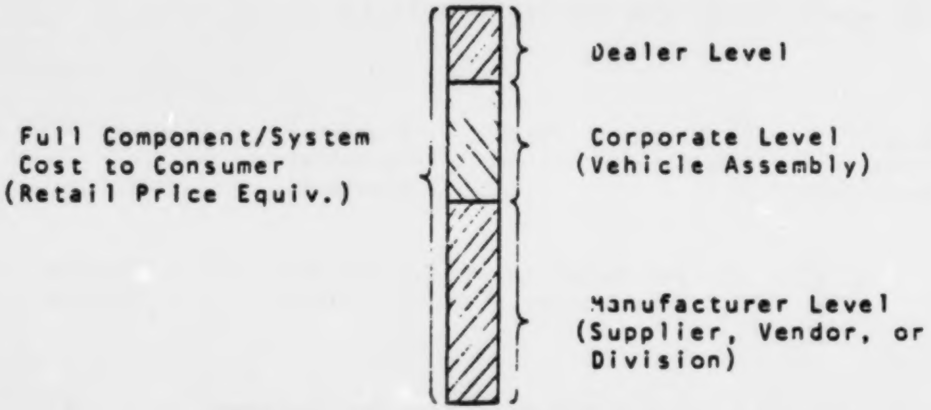

Full Component/System Cost to Consumer (Retail Price Equiv.)
Dealer Level
Corporate Level (Vehicle Assembly)
Manufacturer Level (Supplier, Vendor, or Division)

Figure 1 - 3-Level Industrial Makeup

It should also be noted that supplier (or vendor) and division can be used synonymously since the cost to the corporate level will be the same even though the division is a part of the corporation. This is because the division is managed as a profit center, that is, the corporation has placed the division in competition with other suppliers as a means of assuring a high level of efficiency. Therefore, the division's transfer price as it is called is the same as an independent supplier's price to the vehicle manufacturer.

With the three levels of industry making up the major elements of cost to the consumer, or, as used in this study, retail price equivalent, the basic formula is:

$$\begin{aligned}
\begin{matrix}\text{Retail}\\\text{Price}\\\text{Equivalent}\end{matrix} = & \Bigg\{\left[\begin{matrix}\text{Direct}\\\text{Material}\end{matrix} + \begin{matrix}\text{Direct}\\\text{Labor}\end{matrix} + \begin{matrix}\text{Fixed \&}\\\text{Variable}\\\text{Overhead}\end{matrix}\right] \\
& \times \left[1 + 0.2 \begin{matrix}\text{for Corporate}\\\text{Allocation}\end{matrix} + 0.2 \begin{matrix}\text{for Supplier}\\\text{Profit}\end{matrix}\right] + \begin{matrix}\text{Tooling}\\\text{Expense}\end{matrix} + \begin{matrix}\text{Land \&}\\\text{Buildings}\\\text{Expense}\end{matrix}\Bigg\} \\
& \times \Bigg\{1 + 0.2 \begin{matrix}\text{for Corporate}\\\text{Allocation}\end{matrix} + 0.2 \begin{matrix}\text{for Corporate}\\\text{Profit}\end{matrix} \\
& \quad + 0.4 \begin{matrix}\text{for Dealer}\\\text{Overhead \&}\\\text{Profit}\end{matrix}\Bigg\} + \begin{matrix}\text{Research \&}\\\text{Development}\end{matrix} + \begin{matrix}\text{Tooling}\\\text{Expense}\end{matrix}
\end{aligned}$$

Or, in abbreviated form:

$$RPE = \Big\{\big[DM + DL + OH\big]\big[1.4\big] + TE + LBE\Big\}\Big\{1.8\Big\} + RD + TE$$

Direct materials entail those materials of which a given component is comprised. Where possible actual weights of materials were used, but in some instances, estimates based on drawings and sketches were made necessary because of a lack of data. To determine the cost of materials, prices per unit weight as quoted in American Metal Market* were used plus 10%** to account for material waste and scrappage.

Direct labor includes the cost of laborers directly involved in the fabrication of a given component. It has been determined by using standard industrial engineering data and procedures.

Overhead includes both the fixed and variable components of overhead. The fixed portion includes supervisory salaries, building maintenance, heat, power, lighting, and other costs which are substantially unaffected by production volume while the variable portion includes small expendable tools, devices, and materials used in production, repairs and maintenance made to machines directly involved, and other overhead costs which tend to vary with production volume. A straight 40% of the direct labor amount is used to determine all overhead costs.

---

* Metal Working News Edition

** Two exceptions are noteworthy: 1) exhaust systems assume approximately 35% scrappage, and 2) noble metals used in catalysts assume no waste or scrappage.

A figure of 20% applied to the sum of material, labor, and overhead costs is used to determine corporate allocation, in other words, the amount needed to cover the supplier's support from its front office. Also to the sum of material, labor, and overhead costs, a figure of 20% is applied to determine the supplier's profit, approximately half of which is used to pay corporate taxes with the remaining portion being divided between dividend disbursements to stockholders and retained earnings, which are used to finance working capital requirements (increases in current assets and/or decreases in current liabilities) and/or new capital expenditures (long-term assets).

Tooling expense consists of four components: one year recurring tooling expenses (tool bits, disposable jigs and fixtures, etc.); three year non-recurring tooling expenses (dies, etc.); twelve year machinery and equipment expenses; and twelve year launching costs (machinery foundations and other incidental set-up costs) which have been assumed to be 10% of the cost of machinery and equipment.

The construction of new production facilities has been assumed in some cases and their cost is amortized over 40 years. In most instances, however, space in existing facilities was assumed to have been made available for production purposes and, hence, is covered in the overhead costs.

The sum of the above costs, that is, material, labor, plant overhead, tooling expense, corporate allocation, and profit, makes up the price (or, in the case of a division, transfer price) which the supplier charges the vehicle manufacturer for a given component. At the vehicle assembly level, 20% of this price is charged or allocated for the vehicle manufacturer's corporate level support and 20% for corporate profit. To this is added research and development costs. (R & D may not wholly reflect all vehicle certification costs.) Also, a figure of 40% is applied to the supplier price to account for the dealer's margin which includes sales commissions, overhead, and profit.

Because of the need, in many instances, to make modifications to the engine or body to incorporate a component and to assemble it into a vehicle, these have also been accounted for at the division level and transferred to the corporate level at vehicle assembly.

Production volume is a very important assumption since it dictates not only over what number of units costs will be amortized or spread but also on what scale production will take place, in other words, the types and costs of machinery and equipment that will be involved. For this reason, the retail price equivalent estimates determined in this study are meaningless unless they are qualified with their associated production volume and are accurate only within some relevent range of volumes around that production volume.

In some instances, more than one production volume is assumed for the various individual parts making up a given component or system. This results from the assumption of necessary economies of scale for these parts where the vehicle manufacturer is not the only customer for whom they are produced. For example, hoses are frequently produced at higher unit volumes in order to satisfy more than just a single customer or market.

By discounting aftermarket selling prices, when available, by between 1/4 to 1/5, bracketing of the supplier's price had been expected to serve as a check against these estimates. However, because of differences between the assumptions inherent in this study and in actual production, variations may exist. It is assumed that these differences result from a given component either being of a somewhat proprietary nature and hence priced higher than assumed here (possibly, at what the market will bear) or are a result of subtle changes, for whatever reason, which do not allow full maximization of available economies of scale or a combination of the above two reasons.

All of the RPE estimates contained herein are by definition subject to some error. Where little physical description was available, a "best guess" effort was made and naturally these estimates are subject to more error. But, in general, those shown in greater detail are expected to be somewhat more accurate. To those critics who have significant disagreements with these estimates, it can be assumed that either their production assumptions are not at these assumed economies of scale or else they vary with respect to other specific assumptions made in this study regarding tooling costs, amortization schedules, profit level, etc., however, it is expected that a number of vehicle manufacturers may be below these estimates and a similar number above.

IA - SECONDARY AIR INJECTION SYSTEMS
HEAVY DUTY GASOLINE ENGINES

The detailed descriptions and calculations following this page apply to passenger car parts, reprinted from a previous report EPA - 78 - 002, March, 1978. The costs shown therein have been adjusted by using factors, described later in this report, that reflect differences in size and in manufacturing volume (economy of scale) between automobiles and trucks. The EOS used for automobiles is 350,000 per year; for trucks, 50,000.

The resulting retail price equivalent costs for trucks are shown below.

1. Air Pump System

	Automobile Unit Cost	EOS* Factor
Material	7.83	1.3
Labor and Overhead	3.00	2.7
Equipment	.30	2.4
Tooling	.66	3.4
Weighted EOS Factor		1.8
X Automobile Retail Price Equivalent		$31.88
= Truck Retail Price Equivalent		$57.38

* 350,000/50,000 = 2.81 Doublings

Air Injection System

Air Pump Systems--American Motors Air Guard, Chrysler Air Injection, Ford Thermactor & General Motors Air Injection Reactor (A.I.R.)

All air pump systems, Figures 1 and 2, consist of an air injection pump, air injection tubes (one for each cylinder), a mixture control or backfire by-pass valve (added in 1966, '67), a diverter or air by-pass valve (added in 1968), check valves (one for in-line engines, two for V-8 engines), air manifolds, pipes and hoses necessary to connect the various components.

Carburetors and distributors for engines with an air pump system are designed especially for these engines; and, they should not be interchanged with, or replaced by, carburetors or distributors for engines without the air pumps.

The air injection pump, Figures 3, 4, and 5, compresses the air and injects it through the air manifolds, hoses, and injection tubes into the exhaust system, in the area of the exhaust valves. The fresh air burns with the unburned portion of the exhaust gases, thus minimizing CO and HC content of the exhaust.

The mixture control or backfire by-pass valve, when triggered by a sharp increase in manifold vacuum (as when the throttle is suddenly closed), supplies the intake manifold with fresh filtered air, to lean out the fuel-air mixture and prevent exhaust system backfire.

The diverter or air by-pass valve, Figures 6 and 7, when similarly triggered by a sharp increase in manifold vacuum, shuts off the injected air to the exhaust ports; and, helps to prevent backfiring during this period, when the mixture is exceptionally rich. During engine overrun, all the air from the pump is dumped through the muffler on the diverter or air by-pass valve. At high engine speeds, the pump produces more air than the engine can use, and the excess is dumped through the pressure relief valve, when that valve is part of the air pump, Figures 3 and 4, or, through the diverter or air by-pass valve when the pressure relief valve is part of that valve, Figure 7.

The check valve or valves prevent exhaust gases from entering and damaging the air injection pump, as back flow can occur even under normal operating conditions.

When properly installed and maintained, the system will effectively reduce exhaust emissions. However, if any system components or any engine component that operates in conjunction with the air pump system should malfunction, exhaust emissions might increase.

Because of the relationship between engine operating condition and unburned exhaust gases, the condition of the engine and tune-up should be checked whenever the air pump system seems to be malfunctioning. Particular care should be taken in checking items that affect fuel-air ratio, such as crankcase ventilation system (PCV), the carburetor and carburetor air cleaner.

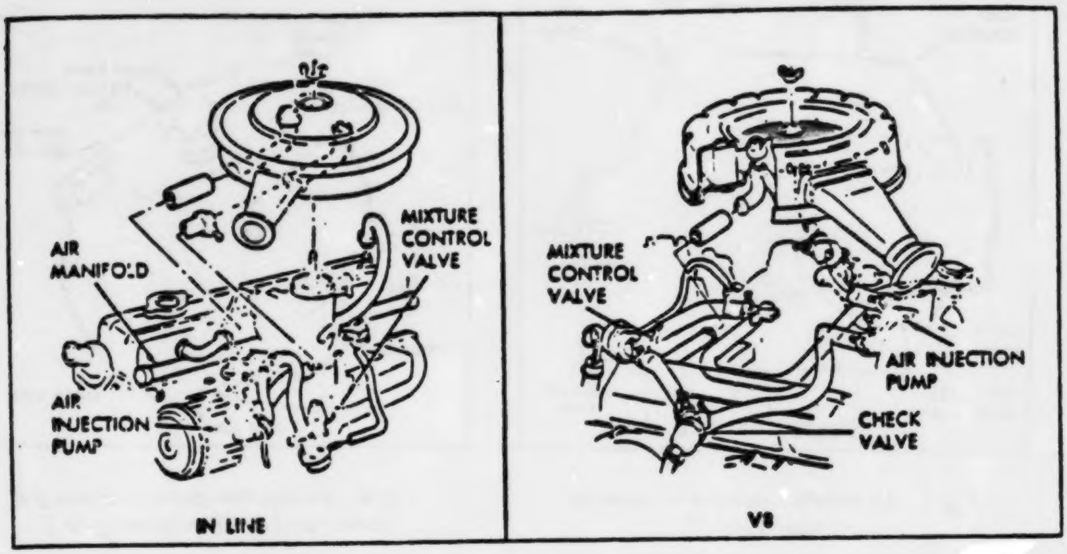

air
MIXTURE CONTROL VALVE
AIR MANIFOLD
AIR INJECTION PUMP
IN LINE
MIXTURE CONTROL VALVE
AIR INJECTION PUMP
CHECK VALVE
V8

Fig. 1 Typical installation of an air pump system with a mixture control valve, otherwise known as a backfire by-pass valve

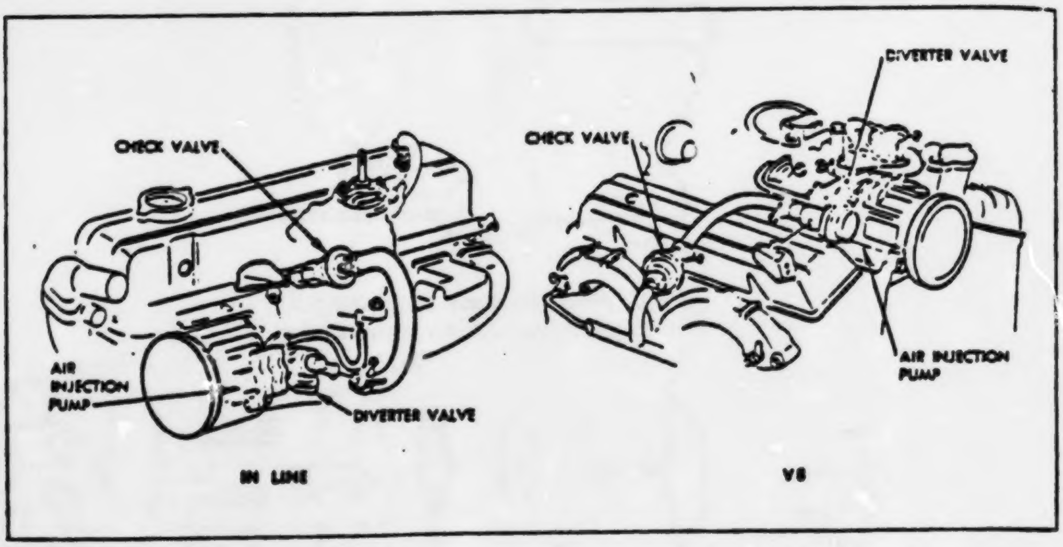

CHECK VALVE
AIR INJECTION PUMP
DIVERTER VALVE
IN LINE
DIVERTER VALVE
CHECK VALVE
AIR INJECTION PUMP
V8

Fig. 2 Typical installation of an air pump system with a diverter valve, otherwise known as an air by-pass valve. 1968-73

Air Injection Systems

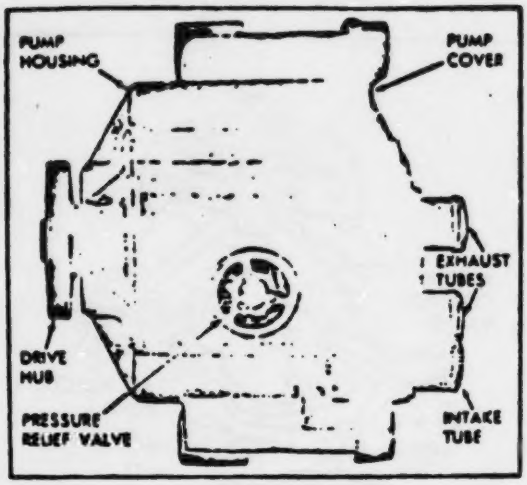

PUMP HOUSING
PUMP COVER
EXHAUST TUBES
DRIVE HUB
PRESSURE RELIEF VALVE
INTAKE TUBE

Fig. 3 Air injection pump with separate air filter. 1966-67

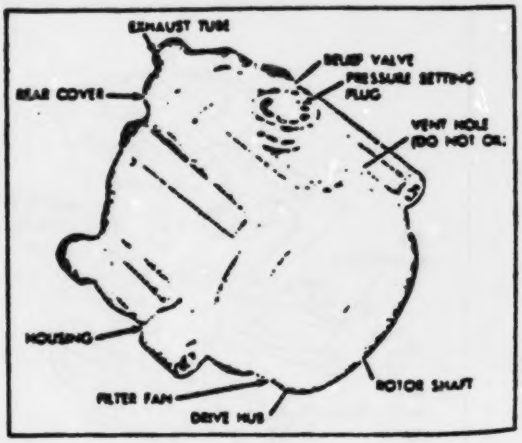

EXHAUST TUBE
RELIEF VALVE
PRESSURE SETTING PLUG
REAR COVER
VENT HOLE (DO NOT OIL)
HOUSING
ROTOR SHAFT
FILTER FAN
DRIVE HUB

Fig. 4 Air injection pump with integral centrifugal air filter. Starting 1968

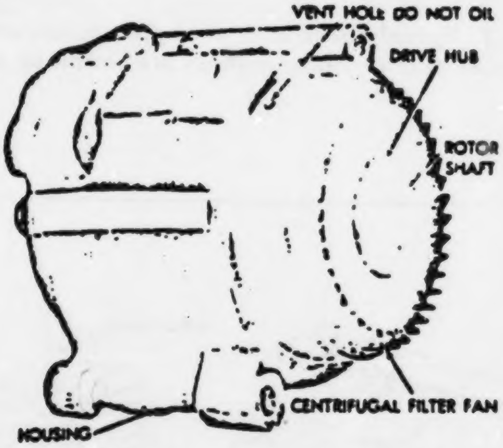
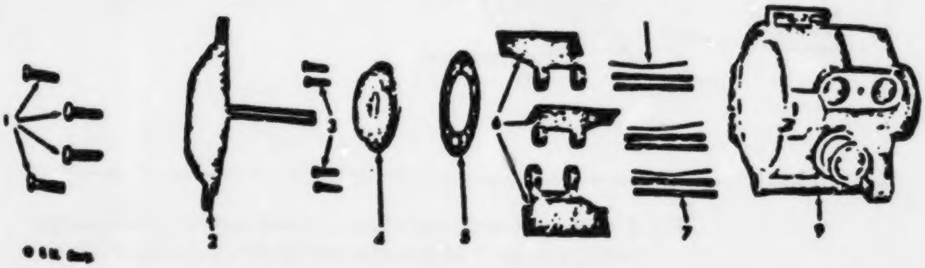

VENT HOLE DO NOT OIL
DRIVE HUB
ROTOR SHAFT
CENTRIFUGAL FILTER FAN
HOUSING

Fig. 5 Air injection pump with integral centrifugal air filter without pressure valve


1
2
3
4
5
6
7
9
© G.M. Corp.

All injection pump—exploded view

1 Cover attaching bolts
2 Cover assembly
3 Rear rotor ring screws
4 Rear rotor ring and bearing assembly
5 Rear carbon seal
6 Vane assemblies
7 Vane shoes
8 Shoe springs
9 Housing and assemblies

Air Injection Systems

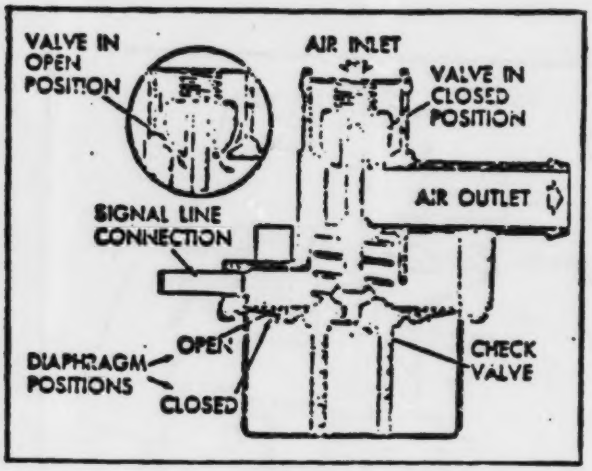

VALVE IN OPEN POSITION
AIR INLET
VALVE IN CLOSED POSITION
AIR OUTLET
SIGNAL LINE CONNECTION
OPEN
DIAPHRAGM POSITIONS
CLOSED
CHECK VALVE

Fig. 6. Typical mixture control or backfire by-pass valve

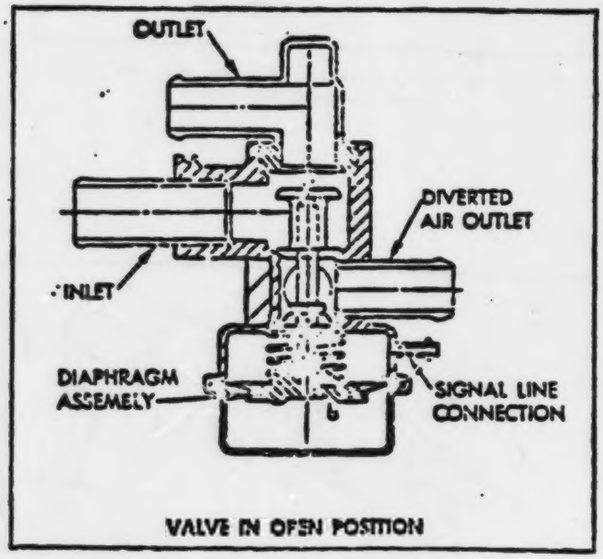

OUTLET
DIVERTED AIR OUTLET
INLET
DIAPHRAGM ASSEMBLY
SIGNAL LINE CONNECTION
VALVE IN OPEN POSITION

Fig. 7 Typical diverter or air by-pass valve

Air Injection Systems

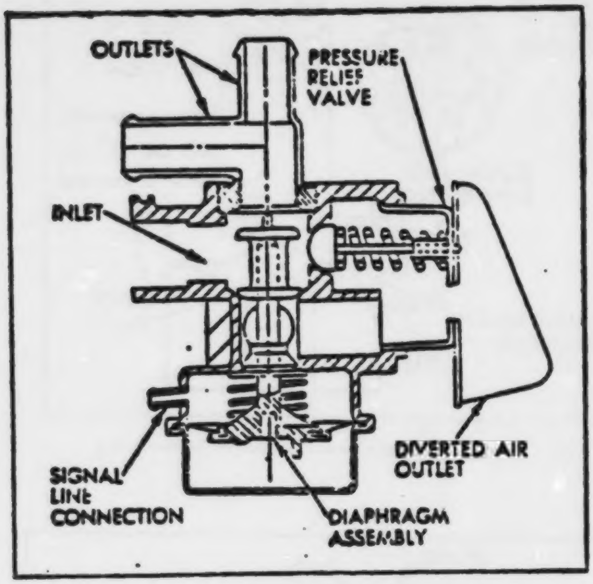

OUTLETS
PRESSURE RELIEF VALVE
INLET
DIVERTED AIR OUTLET
SIGNAL LINE CONNECTION
DIAPHRAGM ASSEMBLY

Fig. 8 Typical diverter or air by-pass valve with integral pressure relief valve

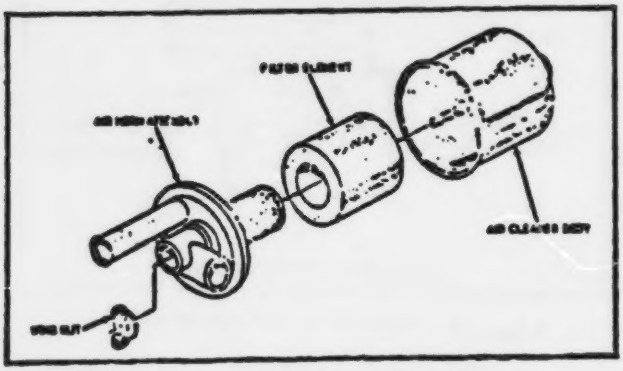
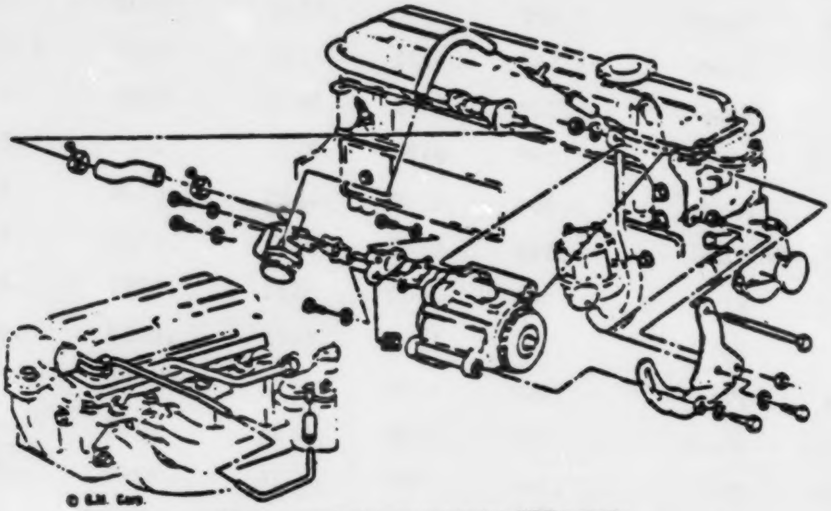

FILTER ELEMENT
AIR CLEANER BODY
WING NUT

Fig. 9 Conventional type pump air filter

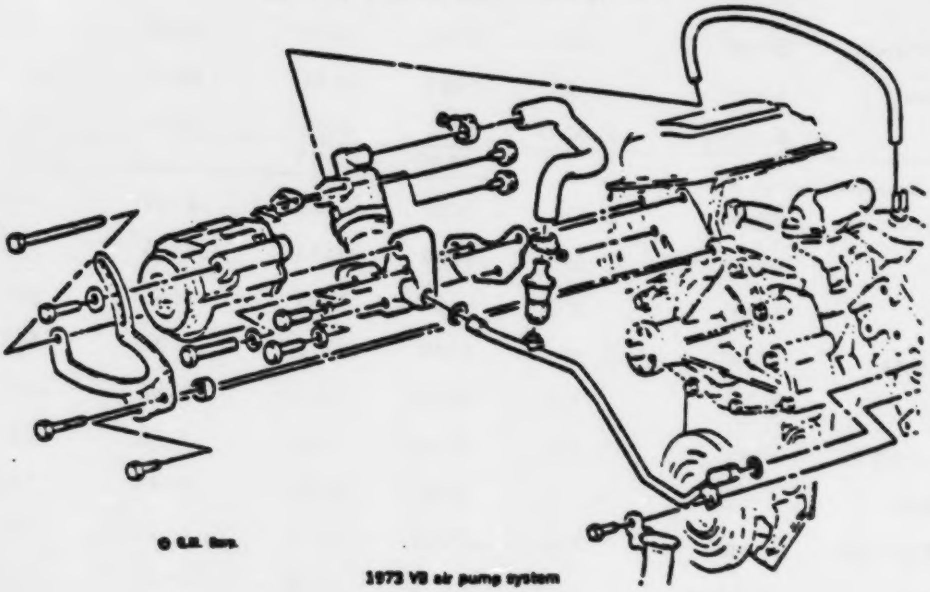
Pontiac

'Fig. 10 - AIR PUMP SYSTEM—CONT'D



© G.M. Corp.

1973 six cylinder air pump installation. 1972 is similar



© G.M. Corp.

1973 V8 air pump system

Air Injection System

BILL OF MATERIAL

	Material	Weight	Mat Costs	Labor	Labor Overhead	Mfg Costs	Reference
Pump Assem	Assem	7.690	-	.1250	.0500	.1750	07817806
Housing	Alum	3.500	2.1000	.1250	.0500	2.2750	
Hub	Steel	.200	.0400	.0625	.0250	.1275	
Shaft	Steel	.090	.0180	.0312	.0125	.0617	
Cover	Alum	1.000	.6000	.0625	.0250	.6875	
Rotor	PM Steel	.300	.0600	.0312	.0125	.1037	
Bearings	Steel	.400	.2000	.0625	.0250	.2875	
Vanes	PM	.300	.1200	.0625	.0250	.2075	
Vane Shoes	PM	.100	.0400	.0312	.0125	.0837	
Shoe Springs	Steel	.050	.0100	.0156	.0062	.0318	
Carbon Seal	PM	.100	.0400	.0156	.0062	.0618	
Tubes	Steel	.300	.0600	.0156	.0062	.0818	
Relief Valve	Steel	.150	.0300	.1250	.0500	.2050	
Hardware	Steel	.200	.0400	.0156	.0062	.0618	
Fan	Plastic	1.000	.8000	.0625	.0250	.8875	
			4.1580	.8435	.3373	5.3388	
Air Manifold	Steel	2.000	1.0000	.0625	.0250	1.0875	
Hoses	Rubber	0.500	.1000	.0312	.0125	.1437	
Pipes	Steel	.300	.0600	.0156	.0062	.0818	
A I Tubes	Steel	1.000	.5000	.0312	.0125	.5437	
Pulley	Steel	.950	.1900	.0625	.0250	.2775	03927116
Mtg. Brkt	Steel	2.590	.5180	.0625	.0250	.6055	4027214
Hardware	Steel	1.500	.3000	.0156	.0062	.3218	
A/P Bracket	Steel	.250	.0500	.0312	.0125	.0937	
A/P Belt	Rubber	.230	.0460	.0156	.0062	.0678	4027350
			2.7640	.3279	.1311	3.2230	

Air Injection System

Valves and Filter

BILL OF MATERIAL

Part	Material	Weight	Mat Costs	Labor	Labor Overhead	Mfg Costs	Reference
Air Pump Filter	Assem	.300		.0312	.0125	.0437	See Sketch
Air Horn	Steel	.100	.0200	.0625	.0250	.1075	
Filter	Paper	.100	.0400	.0312	.0125	.0837	
Body	Steel	.100	.0200	.0156	.0062	.0418	
			.0800	.1405	.0562	.2767	
Mix Contr. Vlv	Assem	.890	-	.1250	.0500	.1750	3769895
Valve	PM	.090	.0360	.0625	.0250	.1235	27.95
Valve Spring	Steel	.100	.0200	.0156	.0062	.0418	
Housing	Steel	.200	.0400	.0625	.0250	.1275	
Diaphragm	Copper	.100	.0800	.0312	.0125	.1237	
Cap	Steel	.200	.0400	.0312	.0125	.0837	
Diaphragm Spr	Steel	.100	.0200	.0156	.0062	.0418	
Pin	Steel	.100	.0200	.0625	.0250	.1075	
			.2560	.4061	.1624	.8245	
Diverter & Relief Valve	Assem	1.230	-	.1250	.0500	.1750	7043229 14.80
Housing	Steel	.500	.1000	.0625	.0250	.1875	3671044
Pin & Valve	Steel	.250	.0500	.0312	.0125	.0937	16.60
Spring	Steel	.125	.0250	.0156	.0062	.0468	
Diaphragm	Copper	.125	.1000	.0312	.0125	.1437	
Relief Valve	PM	.052	.0200	.0312	.0125	.0637	04974265
Rel Vlve Spr	Steel	.063	.0120	.0156	.0062	.0338	4.80
Rel Vlve Cover	Steel	.115	.0230	.0312	.0125	.0667	
			.3300	.3435	.1374	.8109	

Air Injection System and **Bill of Material** (cont'd)

Part	Material	Weight	Mat Costs	Labor	Labor Overhead	Mfg Costs	Reference
Valve Hoses	Rubber	1.000	.2000	.0625	.0250	.2875	
Clamps	Steel	.200	.0400	.0156	.0062	.0618	
Vehicle Assem	-	-	-	.3750	.1500	.5250	
Engine Mod	-	-	-	.1250	.0500	.1750	
Assem Vehicle			.24			1.0493	
Total Vehicle A I-System						3.8111	

Air Injection System--Tooling Costs--Amortization Per Part

Part	Economic Volume	1 Year Recurring Tooling	3 Year Non-Recurring Tooling	12 Year Machinery & Equip	12 Year Launching Costs	40 Year Land & Buildings	Amortization Per Piece
		.0200	.0333	.0400	.0040	.0250	.1223
Pump Assem	5,000,000	100,000	500,000	2,400,000	240,000	5,000,000	
		.0400	.0667	.0833	.0083		.1983
Housing	5,000,000	200,000	1,000,000	5,000,000	500,000		
		.0100	.0200	.0100	.0010		.0410
Hub	5,000,000	50,000	300,000	600,000	60,000		
		.0020	.0020	.0020	.0002		.0062
Shaft	5,000,000	10,000	30,000	120,000	12,000		
		.0100	.0167	.0167	.0017		.0450
Cover	5,000,000	50,000	250,000	1,000,000	100,000		
		.0040	.0020	.0020	.0002		.0082
Rotor	5,000,000	20,000	30,000	120,000	12,000		
		.0050	.0050	.0083	.0008		.0191
Bearings	10,000,000	50,000	150,000	1,000,000	100,000		
		.0040	.0080	.0067	.0007		.0193
Vanes	15,000,000	60,000	360,000	1,200,000	120,000		
		.0010	.0040	.0033	.0003		.0086
Vane Shoes	30,000,000	30,000	360,000	1,200,000	120,000		
		.0007	.0013	.0007	.0001		.0027
Shoe Springs	30,000,000	20,000	120,000	240,000	24,000		
		.0020	.0020	.0020	.0002		.0062
Carbon Seal	5,000,000	10,000	30,000	120,000	12,000		
		.0013	.0008	.0003	-		.0028
Tubes	15,000,000	20,000	36,000	60,000	6,000		
		.0100	.0080	.0060	.0006		.0246
Relief Valve	5,000,000	50,000	120,000	360,000	36,000		
		.0067	.0067	.0056	.0006		.0194
Hardware	15,000,000	100,000	300,000	1,000,000	100,000		
		.0040	.0024	.0020	.0002		.0086
Fan	5,000,000	20,000	36,000	120,000	12,000		
							.5323

Air Injection System--Tooling Costs--Amortization Per Part

Part	Economic Volume	1 Year Recurring Tooling	3 Year Non-Recurring Tooling	12 Year Machinery & Equip	12 Year Launching Costs	40 Year Land & Buildings	Amortization Per Piece
		.0100	.0067	.0042	.0004	-	.0212
Air Manifold	1,000,000	10,000	20,000	50,000	5,000		
		.0040	.0017	.0025	.0002		.0084
Hoses	5,000,000	20,000	25,000	150,000	15,000	-	
		.0020	.0008	.0008	.0001		.0038
Pipes	5,000,000	10,000	12,500	50,000	5,000	-	
		.0060	.0060	.0020	.0002		.0142
A I Tubes	5,000,000	30,000	90,000	120,000	12,000	-	
		.0100	.0050	.0025	.0002		.0177
Pulley	2,000,000	20,000	30,000	60,000	6,000		
		.0100	.0050	.0025	.0002		.0177
Mtg Bracket	2,000,000	20,000	30,000	60,000	6,000		
		.0100	.0040	.0020	.0002		.0162
Hardware	5,000,000	50,000	60,000	120,000	12,000		
		.0100	.0050	.0025	.0002		.0177
A/P Bracket	2,000,000	20,000	30,000	60,000	6,000		
		.0020	.0020	.0010	.0001		.0051
A/P Belt	5,000,000	10,000	30,000	60,000	6,000		
		.0640	.0362	.0200	.0018		.1220
		.0020	.0020	.0010	.0001		.0051
Air Pump Filter	5,000,000	10,000	30,000	60,000	6,000		
		.0040	.0040	.0020	.0002		.0102
Air Horn	5,000,000	20,000	60,000	120,000	12,000		
		.0040	.0040	.0020	.0002		.0102
Filter	5,000,000	20,000	60,000	120,000	12,000		
		.0040	.0040	.0020	.0002		.0102
Body	5,000,000	20,000	60,000	120,000	12,000		
		.0140	.0140	.0070	.0007		.0357

Air Injection System--Tooling Costs--Amortization Per Part

	Economic Volume	1 Year Recurring Tooling	3 Year Non-Recurring Tooling	12 Year Machinery & Equip	12 Year Launching Costs	40 Year Land & Buildings	Amortization Per Piece
		.0100	.0100	.0020	.0002		.0222
Mix Cont Valve	2,500,000	25,000	75,000	60,000	6,000	-	
		.0100	.0100	.0040	.0004		.0244
Valve	2,500,000	25,000	75,000	120,000	12,000		
		.0020	.0020	.0010	.0001		.0051
Valve Spring	5,000,000	10,000	30,000	60,000	6,000		
		.0100	.0100	.0040	.0004		.0244
Housing	2,500,000	25,000	75,000	120,000	12,000		
		.0040	.0040	.0020	.0002		.0102
Diaphragm	2,500,000	10,000	30,000	60,000	6,000		
		.0100	.0100	.0020	.0002		.0222
Cap	2,500,000	25,000	75,000	60,000	6,000		
		.0100	.0020	.0010	.0001		.0131
Diaphragm Spr	5,000,000	50,000	30,000	60,000	6,000		
		.0020	.0020	.0006	.0001		.0047
Pin	5,000,000	10,000	30,000	36,000	3,600		
		.0580	.0500	.0166	.0017		.1263
		.0100	.0100	.0020	.0002		.0222
Div & Rel Valve	2,500,000	25,000	75,000	60,000	6,000		
		.0100	.0100	.0040	.0004		.0244
Housing	2,500,000	25,000	75,000	120,000	12,000		
		.0200	.0200	.0040	.0004		.0444
Pin & Valve	2,500,000	50,000	150,000	120,000	12,000		
		.0020	.0020	.0010	.0001		.0051
Spring	5,000,000	10,000	30,000	60,000	6,000		
		.0040	.0040	.0020	.0002		.0102
Diaphragm	2,500,000	10,000	30,000	60,000	6,000		
		.0100	.0100	.0020	.0002		.0222
Relief Valve	5,000,000	50,000	150,000	120,000	12,000		
		.0020	.0020	.0010	.0001		.0051
Rel Valve Spr	5,000,000	10,000	30,000	60,000	6,000		
		.0040	.0040	.0020	.0002		.0102
Rel Vlve Cover	2,500,000	10,000	30,000	60,000	6,000		
		.0620	.0620	.0180	.0018		[illegible]

Air Injection System

Tooling Costs

Amortization Per Part

Part	Economic Volume	1 Year Recurring Tooling	3 Year Non-Recurring Tooling	12 Year Machinery & Equip	12 Year Launching Costs	40 Year Land & Buildings	Amortization Per Piece
Valve Hoses	5,000,000	.0020 10,000	.0020 30,000	.0020 120,000	.0002 12,000	-	.0062
Clamps	10,000,000	.0050 50,000	.0050 150,000	.0030 360,000	.0003 36,000	-	.0133
Vehicle Assem	300,000	.1000 30,000	.1000 90,000	.1000 360,000	.0100 36,000	-	.3100
Engine Mod	300,000	.1000 30,000	.1000 90,000	.1000 360,000	.0100 36,000	-	.3100
Assem Vehicle							.6395
Total A I System							1.5996

Air Injection System

TOTAL MANUFACTURING COSTS

Part	Mat	Labor	Plant Over-Head	Plant Costs	Tooling Exp.	Tooling Inv.	.20 MC Corp	.20 MC Corp Profit	Mfg/ Vendor Costs
Pump	3.3280	.5310	.2124	4.0714	.2085	.1489	.8143	.8143	6.0574
Pump Assem	.0000	.1250	.0500	.1750	.0533	.0690	.0350	.0350	.3673
Relief Valve	.0300	.1250	.0500	.2050	.0180	.0066	.0410	.0410	[illegible]
Fan	.8000	.0625	.0250	.8875	.0064	.0022	.1775	.1775	[illegible]
Air Manifold	1.0000	.0625	.0250	1.0875	.0167	.0046	.2175	.2175	1.5438
Hoses	.1000	.0312	.0125	.1437	.0057	.0027	.0287	.0287	.2095
Pipes & Tubes	.5600	.0468	.0187	.6255	.0148	.0031	.1251	.1251	.8936
Pulley	.1900	.0625	.0250	.2775	.0150	.0027	.0555	.0555	.4062
Belt	.0460	.0156	.0062	.0678	.0040	.0011	.0135	.0135	.1000
Mktg. Brkts.	.5680	.0937	.0375	.6992	.0300	.0054	.1398	.1398	1.0143
Hardware	.3000	.0156	.0062	.3218	.0140	.0022	.0644	.0644	.4667
Air Injec & Pump	6.9220	1.1714	.4685	8.5619	.3864	.2485			12.6215
Air Pump Filter	.0800	.1405	.0562	.2767	.0280	.0077	.0553	.0553	.4231
Mix Contr Vlve	.2560	.4061	.1624	.8245	.1080	.0183	.1649	.1649	1.2006
Diverter & Relief Valve	.3300	.3435	.1374	.8109	.1240	.0198	.1622	.1622	1.2791
Valve Hoses	.2000	.0625	.0250	.2875	.0040	.0022	.0575	.0575	.4087
Clamps	.0400	.0156	.0062	.0618	.0100	.0033	.0124	.0124	.0999
Total AI System									15.1128

Air Injection System

RETAIL PRICE EQUIVALENT
AT THE VEHICLE LEVEL

Part	Plant Vendor Costs	R&D	Tools & Equip	Corp. Alloc	Corp. Profit	Dealer Markup	Vehicle Retail Price Equivalent
AI Pump	12.6215	1.000		2.5243	2.5243	5.0485	23.7187
AI Valves	3.4913	-	-	.6983	.6983	1.3965	6.2843
Vehicle Assem	.5250	-	.3100	.1050	.1050	.2100	1.2550
Engine Mod.	.1750	-	.3100	.0350	.0350	.0700	.6250
Total Vehicle Retail Price Equivalent							31.8830

R & D is estimated to be $300,000 per year. Allocated over 300,000 vehicles per year results in $1.00 per vehicle.

Air Injection System

Cost Comparison to Aftermarket Selling Prices

Using the aftermarket discount data and the aftermarket selling prices, the Air Injection System costs are:

		Disc 1/4	Disc 1/5	Estimated Vendor Costs
Air Pump Assembly	62.95	15.74	12.59	7.9874
Pulley	2.64	.66	.53	.4062
Bracket Assembly	3.60	.90	.72	1.0143
Diverter Valve	11.80	2.95	2.36	1.2791
Mixture Control Valve	14.00	3.50	2.80	1.2806

Air Injection System
Cost Methodology

The weight data were obtained from both the Chrysler data and the Oldsmobile data books. The material costs are compiled using the AMM mill prices.

The labor costs are estimates based on mass production tooling and equipment. The economies of scale are specified in the tooling estimates. The overhead data are based on the information supplied from one of the automobile companies.

The tooling costs are based on mass production estimates of die, mold, and fixture costs. The equipment estimates are based on the current costs of new equipment. The land and building estimate is based on published information, on an actual production facility for General Motors.

Air Injection System

The installations in various engines, depending upon company, vary significantly. Therefore, each system cost can be constructed from the prior detail data. See the installation sketches to confirm the data.

HEAVY DUTY GASOLINE ENGINES

2. Air Switching System

The detailed descriptions and calculations following this page apply to passenger car parts, reprinted from a previous report EPA - 78 - 002, March, 1978. The costs shown therein have been adjusted by using factors, described later in this report, that reflect differences in size and in manufacturing volume (economy of scale) between automobiles and trucks. The EOS used for automobiles is 350,000 per year; for trucks, 50,000.

The resulting retail price equivalent costs for trucks are shown below.

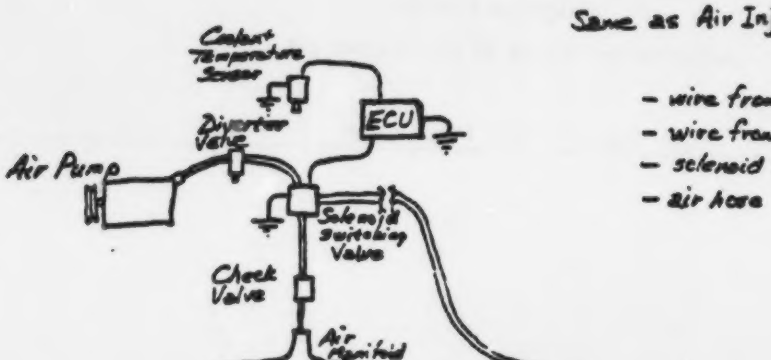
	Automobile Unit Cost	EOS Factor
Material	.163	1.3
Labor and Overhead	.410	2.7
Equipment	.025	2.4
Tools	.033	3.4
Weighted Factor		2.4
X Automobile Retail Price Equivalent		$2.08
= Truck Retail Price Equivalent		$4.99

The air switching system is a subsystem and is usually associated with the 3-way plus oxidation catalyst system. An air switching valve is added to the air injection line which supplies air to the exhaust ports. When engine coolant temperature reaches a predetermined level, the TVS allows a vacuum signal to be sent to the switching valve which in turn diverts the air being injected into the ports to a point downstream of the 3-way catalyst and just upstream of the oxidation catalyst. In vehicles utilizing electronic control units (ECU), the ECU may receive signals from a temperature sensor that indicates when engine temperature is high enough at which time the air is diverted downstream by a solenoid switching valve.

Air Switching System

Same as Air Injection System except:

- wire from CTS to ECU
- wire from ECU to solenoid
- solenoid switching valve
- air hose to point downstream


Coolant Temperature Sensor
ECU
Diverter Valve
Air Pump
Solenoid Switching Valve
Check Valve
Air Manifold
3-Way
Ox Cat

Air Switching System

BILL OF MATERIAL

MANUFACTURING COSTS

Component	Material	Weight	Mat Costs	Labor	Overhead	Mfg Costs	Reference
Solenoid Valve	Steel	.316	.0634	.2620	.1048	.4302	Sketch
Electric Wiring	Plastic Copper	.050	.0400	.0010	.0004	.0414	and EPA Data
Hose	Rubber	.300	.0600	.0300	.0120	.1020	
Total			.1634	.2930	.1212	.5736	
Vehicle Assembly				.0625	.0250	.0875	
Engine Modification				.0312	.0125	.0437	
Total Vehicle						.7048	

Air Switching System--Tooling Costs--Amortized Per Part

Part	Economic Volume Per Year	1 Year Recurring Tooling	3 Year Non-Recurring Tooling	12 Year Machinery Equipment	12 Year Launching Costs	40 Year Land & Buildings	Amortization Per Piece
		.0100	.0167	.0200	.0020		.0487
Solenoid Valve	5,000,000	50,000	250,000	1,200,000	120,000	-	
		.0004	.0002	.0032	.0000		.0009
Wiring	5,000,000	2,000	2,500	15,000	1,500	-	
		.0040	.0017	.0025	.0002		.0084
Hose	5,000,000	20,000	25,000	150,000	15,000	-	
Total		.0144	.0185	.0223	.0023		.0579
		.0083	.0167	.0023	.0003		.0281
Vehicle Assembly	300,000	2,500	15,000	10,000	1,000	-	
		.0167	.0111	.0028	.0003		.0308
Engine Modification	300,000	5,000	10,000	10,000	1,000	-	
Total							.1168

Research and Development Estimate: $210,000 over 3 Years, or $70,000 per year for 300,000 vehicles per year, or .2330 per vehicle

Air Switching System

TOTAL MANUFACTURING COSTS

Part	Mat	Labor	Plant Over-Head	Plant Mfg Costs (MC)	Tooling Exp.	Tooling Inv.	.20/MC Corp Costs	.20/MC Corp Profit	Mfg/ Vendo Costs
Solenoid Valve	.0634	.2620	.1048	.4302	.0267	.0220	.0860	.0860	.6509
Wiring & Hose	.1000	.0310	.0124	.1434	.0063	.0029	.0287	.0287	.2100
Total									.8609

Air Switching System

RETAIL PRICE EQUIVALENT
AT THE VEHICLE LEVEL

Part	Plant Vendor Costs (VC)	R&D	Tools and Equip	Corp Allocation .20 VC	Corp Profit .20 VC	Dealer Markup .40 VC	Vehicle Retail Price Equivalent
Solenoid Valve	.6509	.2330	-	,1302	.0302	.2604	1.4046
Wiring & Hose	.2100	-	-	.0420	.0420	.0840	.3780
Vehicle Assembly	.0875	-	.0281	.0175	.0175	.0350	.1856
Engine Modification	.0437	-	.0308	.0087	.0087	.0175	.1095
Total RPE							2.0777

Air Switching System

Cost Comparison to Aftermarket Selling Prices

This particular valve design does not have an aftermarket price in our source data (1977 catalogs). We can estimate the relative selling price by comparing selling prices for diverter valves and EGR valves ($14.00 - $18.05).

	Diverter	EGR
Aftermarket Selling Price	$14.00	$18.05
Discount (1/4 Selling Price)	3.50	4.51
Discount (1/5 Selling Price)	2.80	3.61

The vehicle retail price equivalent (RPE) is estimated to be 2.0777 while the manufacturing costs are .8609 for the valve and hoses (.6509 for the valve).

Air Switching System
Cost Methodology

The weight data is estimated using similar valve data. The valve design was assumed to be solenoid actuated.

The labor costs are estimates of production costs, using today's technology and assumed economies of scale. The tooling estimates are based on knowledge of the mass production processes and equipment.

The assembly costs and the engine modification costs were included in the costs at the vehicle level.

Air Switching System
Applications In Various Engine Configurations

This air switching system is assumed to be unaffected by engine size.

HEAVY DUTY GASOLINE ENGINE

3. Reed Air Valve

The detailed descriptions and calculations following this page apply to passenger car parts, reprinted from a previous report EPA - 78 - 002, March, 1978. The costs shown therein have been adjusted by using factors, described later in this report, that reflect differences in size and in manufacturing volume (economy of scale) between automobiles and trucks. The EOS used for automobiles is 350,000 per year; for trucks, 50,000.

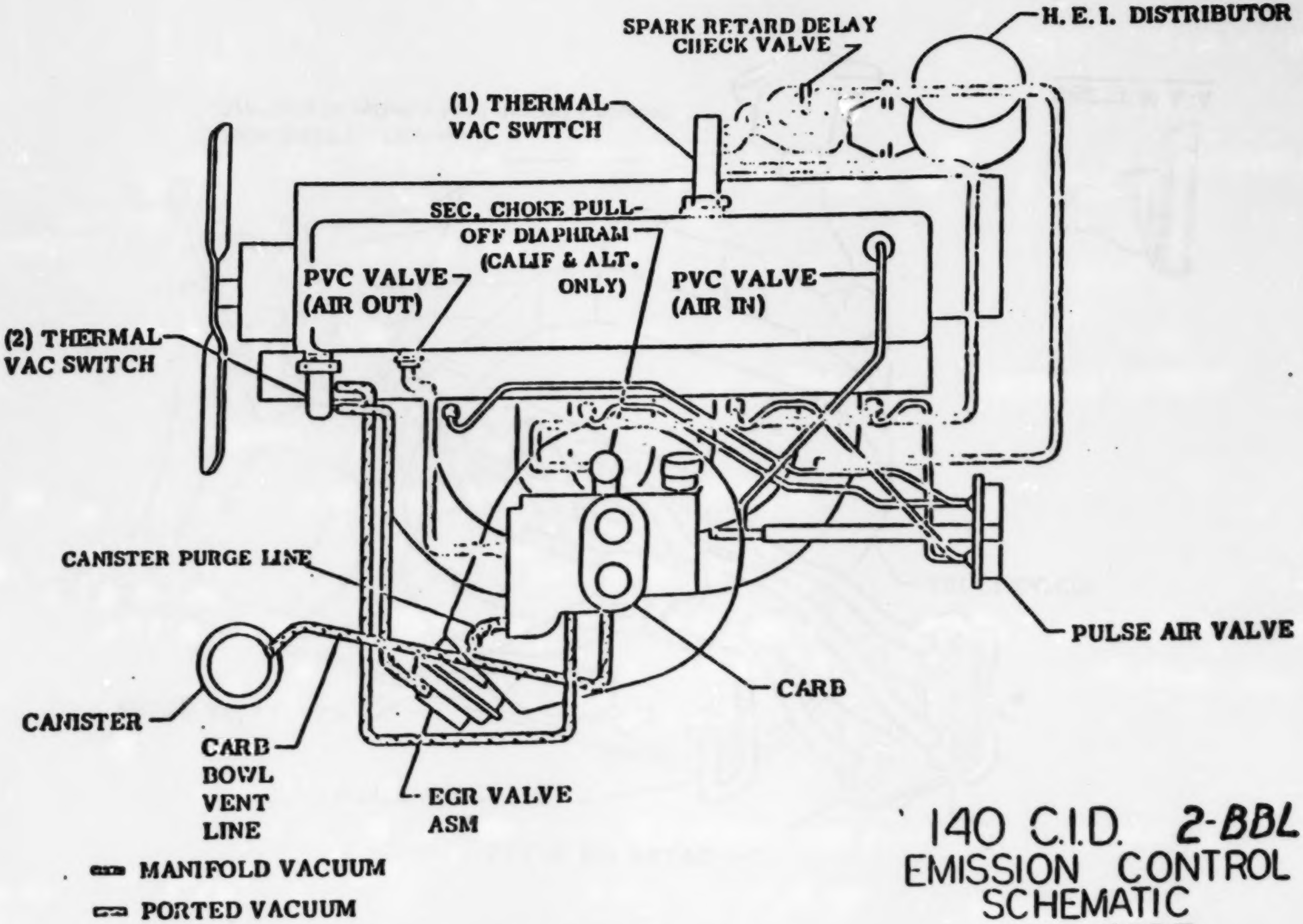
The resulting retail price equivalent costs for trucks are shown below.

	Automobile Unit Cost	EOS Factor
Material	.880	1.3
Labor and Overhead	.335	2.7
Equipment	.024	2.4
Tooling	.077	3.4
Weighted Factor		1.8
X Automobile Retail Price Equivalent		$4.64
= Truck Retail Price Equivalent		$8.35

Reed Air Valve

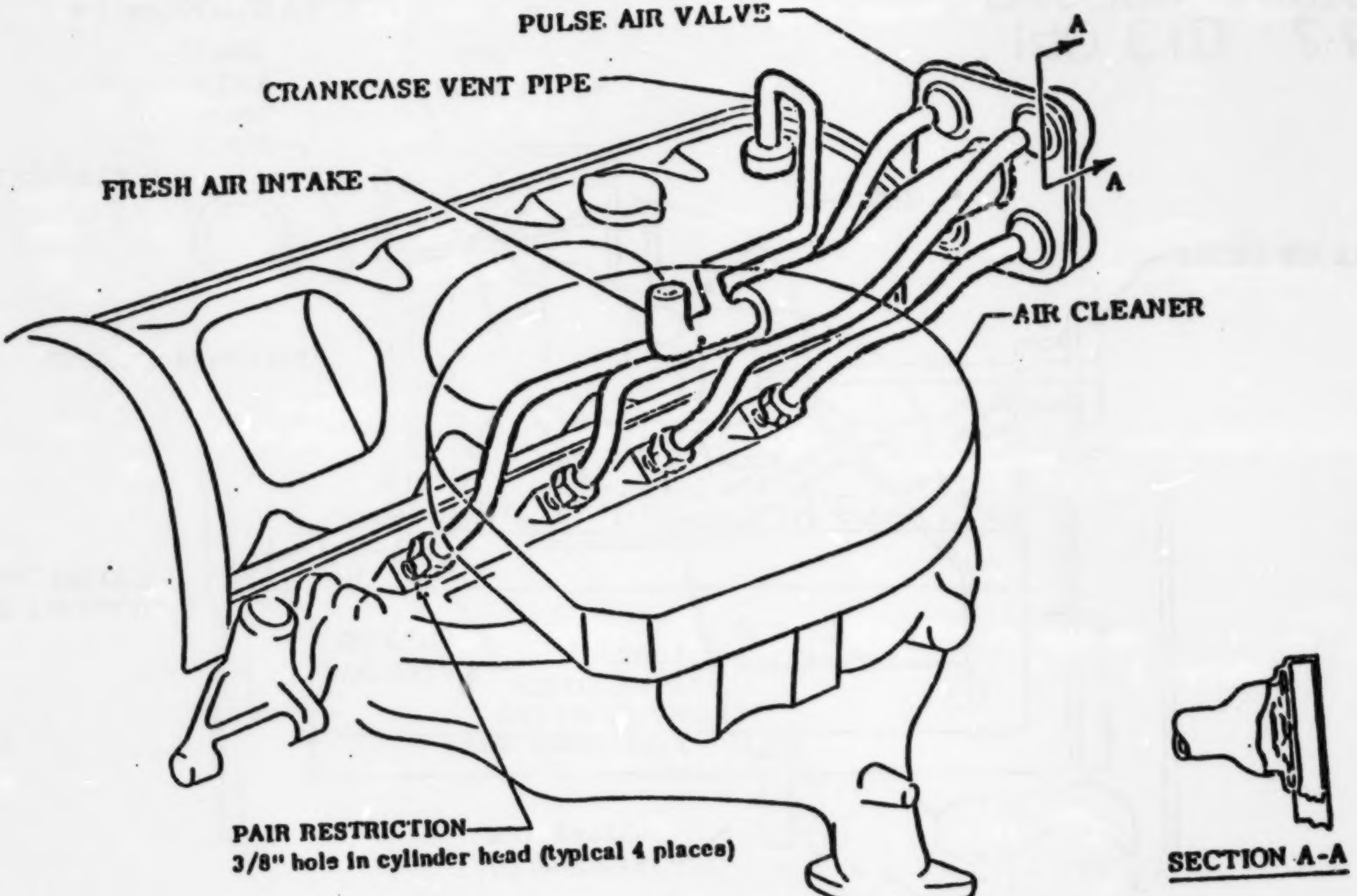
Pulse Air System

The pulse air system is a simplified reed valve system that provides an air supply to the exhaust manifold to help oxidize unburned hydrocarbons and carbon monoxide. The air suction valve takes air from the air cleaner and imposes a pulsated air flow at the exhaust valve. In some applications, this system is used in place of an air pump system when lesser amounts of air are required than which would be provided by an air pump system.


H. E. I. DISTRIBUTOR
SPARK RETARD DELAY CHECK VALVE
(1) THERMAL VAC SWITCH
SEC. CHOKE PULL-OFF DIAPHRAM (CALIF & ALT. ONLY)
PVC VALVE (AIR OUT)
PVC VALVE (AIR IN)
(2) THERMAL VAC SWITCH
CANISTER PURGE LINE
PULSE AIR VALVE
CARB
CANISTER
CARB BOWL VENT LINE
EGR VALVE ASM
▭ MANIFOLD VACUUM
▭ PORTED VACUUM

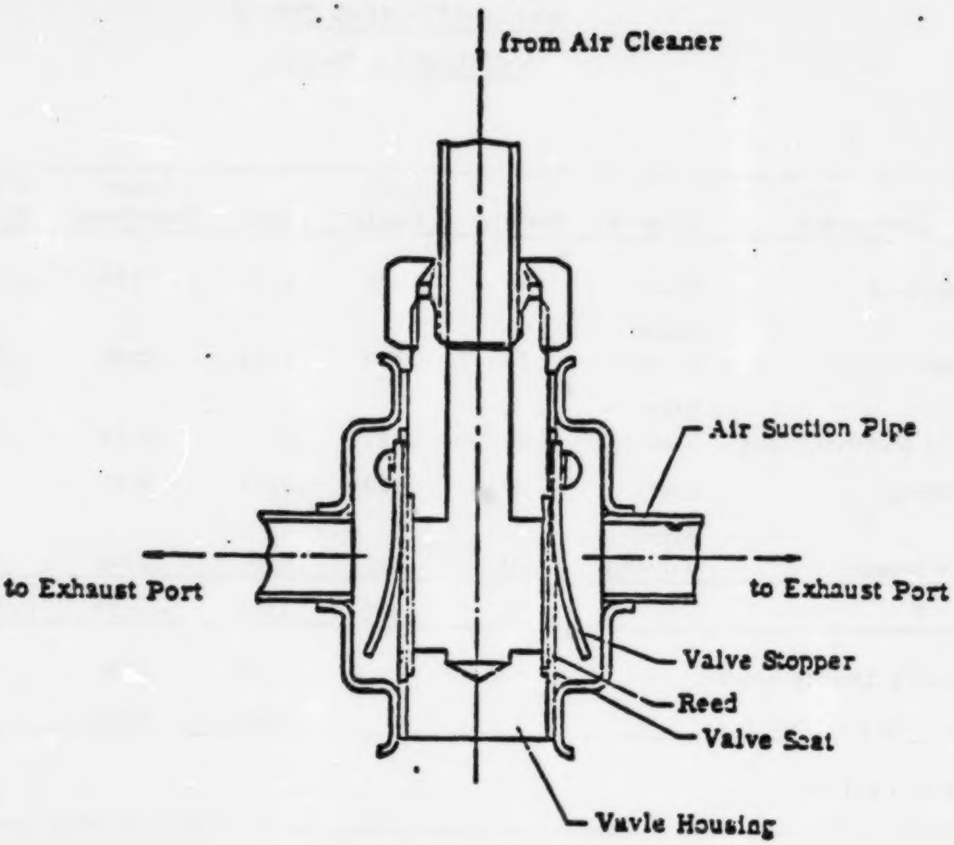
(1) FOR TRAPPED VAC. SPARK & SEC. CHOKE PULL-OFF.
(2) FOR EGR COLD OVERRIDE.

140 C.I.D. 2-BBL
EMISSION CONTROL SCHEMATIC
P-AIR/EGR


PULSE AIR VALVE
A
CRANKCASE VENT PIPE
A
FRESH AIR INTAKE
AIR CLEANER
PAIR RESTRICTION
3/8" hole in cylinder head (typical 4 places)
SECTION A-A

1977 PULSE AIR SYSTEM 140 C.I.D. L4 ENGINE

Air Suction Valve


from Air Cleaner
Air Suction Pipe
to Exhaust Port
to Exhaust Port
Valve Stopper
Reed
Valve Seat
Vavle Housing

· Calibrations : Flow resistance ; 190 - 260 ℓ/min/-500 mmAq
Leak ; Max. 0.2 ℓ/min. /250 mmAq

Reed Air Valve

Pulse Air System

BILL OF MATERIAL
MANUFACTURING COSTS
4-CYLINDER ENGINE

Component	Material	Weight	Mat Costs	Labor	Labor Overhead	Mfg Costs	Reference
Manifold	Alum.	.50	.300	.0416	.0166	.3582	Figure B37
Reed Valve	Steel Bronze	.25	.100	.1250	.0500	.2750	
(6 ft) Suction Pipes	Steel Tubing	1.00	.300	.0312	.0125	.3437	
Fittings	Steel	.30	.120	.0312	.0125	.1637	
Air Intake	Steel Tubing	.20	.060	.0100	.0040	.0740	
		2.25	.880	.2390	.0956	1.2146	
Modify Engine Head	-	-	-	.0625	.0250	.0875	
Vehicle Assembly	-	-	-	.1250	.0500	.1750	
Total Vehicle Installation						1.4771	

Reed Air Valve--Tooling Costs--Amortization Per Part

Part	Economic Volume	1 Year Recurring Tooling	3 Year Non-Recurring Tooling	12 Year Machinery & Equip	12 Year Launching Costs	40 Year Land & Buildings	Amortization Per Piece
Manifold	2,000,000	.0100 20,000	.0100 60,000	.0050 120,000	.0004 10,000	-	.0254
Reed Valve	2,000,000	.0200 40,000	.0100 60,000	.0100 240,000	.0008 20,000	-	.0408
Pipes	10,000,000	.0020 20,000	.0010 30,000	.0010 120,000	.0001 10,000	-	.0041
Fittings	10,000,000	.0050 50,000	.0040 120,000	.0100 1,200,000	.0012 150,000	-	.0202
Air Intake	2,000,000	.0100 20,000	.0050 30,000	.0010 24,000	.0001 2,000	-	.0161
Total		.0470	.0300	.0270	.0026		.1066
Engine Head	400,000	.0500 20,000	.0250 30,000	.0250 120,000	.0025 12,000	-	.1025
Vehicle Assembly	400,000	.0250 10,000	.0250 30,000	.0075 36,000	.0008 3,600	-	.0583
Total Vehicle							.2674

*R&D estimates $900,000 for 3 years, or $.75 per vehicle.

Reed Air Valve

TOTAL MANUFACTURING COSTS

Part	Mat	Labor	Plant Over-Head	Plant Mfg Costs (MC)	Tooling		.20 MC Corp	.20 MC Corp Profit	Mfg/ Vendor Costs
					Exp.	Inv.			
Reed Valve	.880	.2390	.0956	1.2146	.0770	.0236	.2429	.2429	1.8070

Reed Air Valve

RETAIL PRICE EQUIVALENT
AT THE VEHICLE LEVEL

Part	Plant Vendor Costs	R&D	Tools & Equip	Corp. Alloc. .20 VC	Corp. Profit .20 VC	Dealer Markup .40 VC	Vehicle Retail Price Equivalent
Reed Valve	1.8070	.7500	-	.3614	.3614	.7228	4.0027
Engine Mod	.0875	-	.1025	.0175	.0175	.0350	.2600
Assembly	.1750	-	.0583	.0350	.0350	.0700	.3733
Total Vehicle Retail Price Equivalent							4.6360

Reed Air Valve
Cost Comparison to Aftermarket Selling Prices

Using the estimated costs, the aftermarket selling prices could vary between $8.95 and $17.80. No aftermarket data was available at this writing.

Reed Air Valve--Cost Methodology

The weight data was estimated using the sketches supplied by EPA. The material costs are compiled using the 1977 AMM mill prices.

The labor costs are estimates of production costs using today's technology and the assumed economies of scale. The tooling costs are estimates of the expendable tools and the machinery and equipment required to produce the components in a mass production environment.

The assembly costs and the engine modification costs were included in the costs at the vehicle level.

Reed Air Valve--Applications of the System

The applications of the Reed Air Valve systems are on 4-cylinder engines as a substitution of the fan air pump normally used on some 6-cylinder and 8-cylinder engines. We have assumed that this design is limited to 4-cylinder engines.

IB - EXHAUST GAS RECIRCULATION SYSTEMS HEAVY DUTY GASOLINE ENGINES

The detailed descriptions and calculations following this page apply to passenger car parts, reprinted from a previous report EPA - 78 - 002, March, 1978. The costs shown therein have been adjusted by using factors, described later in this report, that reflect differences in size and in manufacturing volume (economy of scale) between automobiles and trucks. The EOS used for automobiles is 350,000 per year; for trucks, 50,000.

The resulting retail price equivalent costs for trucks are shown below.

1. EGR System

	Automobile Unit Cost	EOS Factor
Material	.573	1.3
Labor and Overhead	1.143	2.7
Equipment	.068	2.4
Tooling	.209	3.4
Weighted EOS Factor		2.4
x Automobile Retail Price Equivalent		$7.02
= Truck Retail Price Equivalent		$16.85

Exhaust gas recirculation is used, primarily, to lower peak combustion temperatures, and to control the formation of NOx. NOx emission at low temperatures is not severe; however, when the temperature exceeds about 2,500 °F, the production of NOx in the combustion chamber, is rapidly accelerated to high levels. Peak combustion temperatures can be reduced by retarding the spark, or, by introducing an inert gas such as exhaust gas to dilute the fuel mixture.

A small amount of exhaust gas is required to rapidly cool peak combustion temperatures. Therefore, the hole in the EGR valve is, necessarily, very small even when open to full capacity.

Chrysler, at one time, had one of the simplest exhaust recirculation systems. It had the floor jet under the carburetor. In this system, holes were drilled into the bottom of the intake manifold; then, calibrated jets were screwed into the holes. These holes penetrated the exhaust cross-over passage, allowing exhaust gases to enter the intake manifold constantly. The difficulty inherent in that system was exhaust gas recirculation at idle speeds. This was not only unnecessary for proper emissions control; but, unnecessarily caused rough idling engines. Most Chrysler engines now use a separate EGR valve, similar to those employed by all other manufacturers.

EGR valves are normally mounted on the intake manifold. When the valve opens, exhaust gases are allowed to pass usually from the crossover passage into the throat under the carburetor. The EGR valve is vacuum operated, by intake manifold vacuum on some engines, and by ported vacuum on others.

The ported vacuum systems are the simplest. At idle speeds, the port is avove the throttle blade, keeping the EGR valve closed. When the throttle is opened, vacuum acts on the port, and, the EGR valve opens. At full throttle, there is no intake manifold vacuum. This closes the EGR valve, giving the engine maximum power.

The EGR valve, on some vehicles, is operated by intake manifold vacuum. These valves use an amplifier in the circuit. The amplifier, which is controlled by venturi vacuum, operates the valve. A small hole in the carburetor venturi picks up vacuum, when the airflow through the carburetor is sufficient enough, and, sends the vacuum signal to the amplifier. The amplifier then opens, to allow manifold vacuum to act on the EGR valve. This amplifier system is used to obtain precise timing of EGR valve operations; additionally, exhaust recirculation does not commence, until engine speed is considerable above idle.

However, these systems, were found to be sensitive to outside air temperatures as well; and, were discontinued after March 15, 1973, as a result of the EPA order.

Ford uses a temperature control which resembles a PVS valve, except that it has two nozzles. This control shuts off the vacuum, to the EGR valve, at low temperatures.

When Chrysler stopped locating their air temperature sensor within the plenum chanber, they began using a valve, similar to Ford's, except mounted in the radiator. The Chrysler valve has two nozzles, with a hose connected to one, and a foam filter on the other. At low temperatures the valve opens, allowing air to enter. This weakens the vacuum, thus keeping the EGR valve closed.

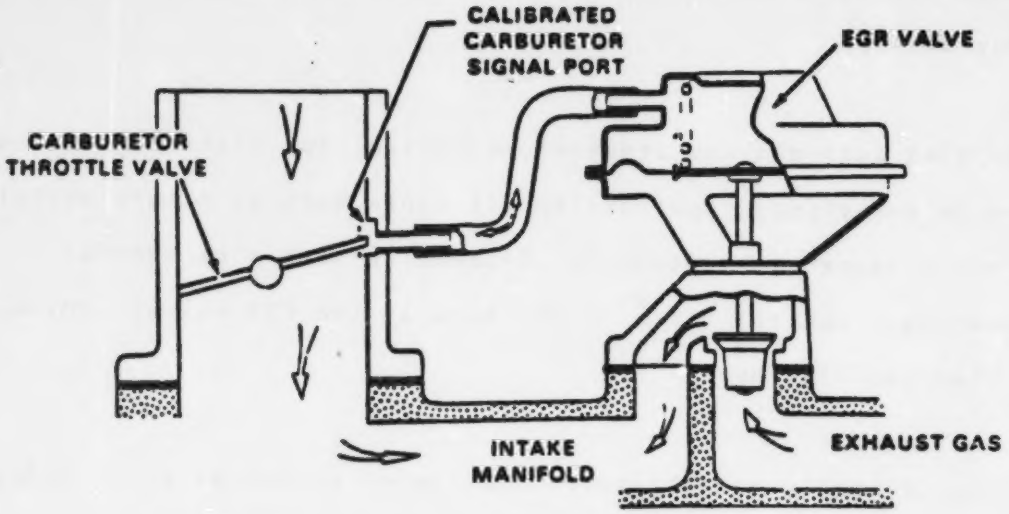
Buick has changed their EGR temperature regulation considerably. In 1972, they did not use a temperature control. In 1973 models, they used a temperature switch, located in the hose that shut off the vacuum to the EGR valve, at low temperatures. This switch was sensitive to engine compartment temperature, and was judged to be a defeat device by EPA. By March 15, 1973, Buick changed the switch to a coolant temperature switch, working with a vacuum solenoid. At low temperatures, this coolant switch caused the solenoid to shut off the vacuum to the EGR valve. In 1974, Buick eliminated the electric components in their system, and employed a straight coolant-vacuum switch, closing off the vacuum to the EGR valve, at low engine temperatures.

Cadillac used a switch in the hose similar to Buick's first switch. After March 15, 1973, they enclosed the switch in a housing; so that, it was more sensitive to engine temperature, rather than underhood temperature.

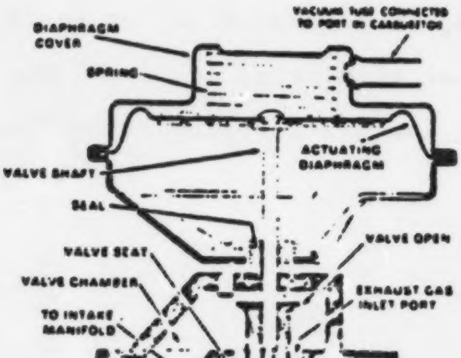
Chevrolet does not use temperature control for their EGR system. This is surprising, considering all other General Motors divisions do use a temperature control. Oldsmobile uses a mechanical temperature control valve in the hose to the EGR valve, similar to what Cadillac uses.

Pontiac probably has the most complicated system of all. Before March 15, 1973, the EGR system was tied in with the transmission control spark system. The two systems were hooked together, so that, when vacuum spark advance was allowed, there was no EGR. When EGR was allowed, there was no vacuum spark advance. This complicated system was eliminated on March 15, 1973; and, from then.on, the EGR and the transmission control spark systems were separate.

EGR Systems

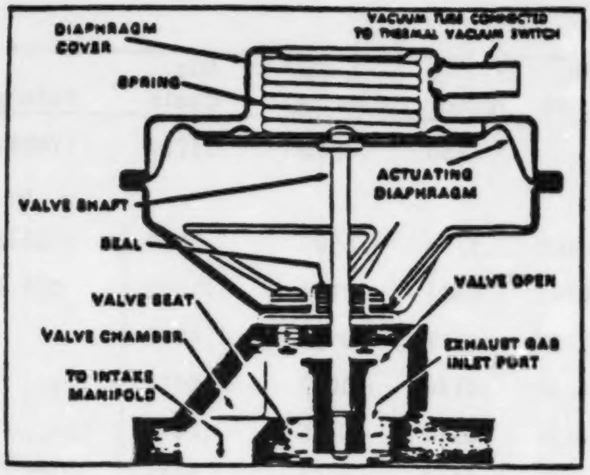

CALIBRATED
CARBURETOR
SIGNAL PORT
EGR VALVE
CARBURETOR
THROTTLE VALVE
INTAKE
MANIFOLD
EXHAUST GAS

Most cars use an EGR system with a valve and a ported vacuum signal, as shown here. Some cars use venturi vacuum with a separate amplifier to operate the valve

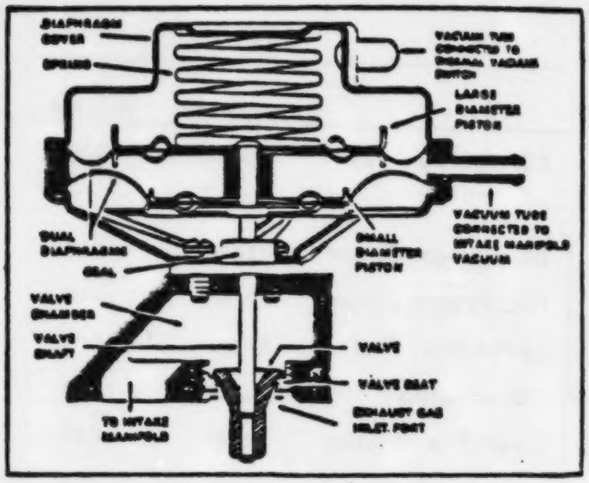

VACUUM TUBE CONNECTED
TO PORT IN CARBURETOR
DIAPHRAGM
COVER
SPRING
ACTUATING
DIAPHRAGM
VALVE SHAFT
SEAL
VALVE OPEN
VALVE SEAT
VALVE CHAMBER
EXHAUST GAS
INLET PORT
TO INTAKE
MANIFOLD

Cutaway of a typical General Motors EGR valve. The Chrysler and Ford valves are similar

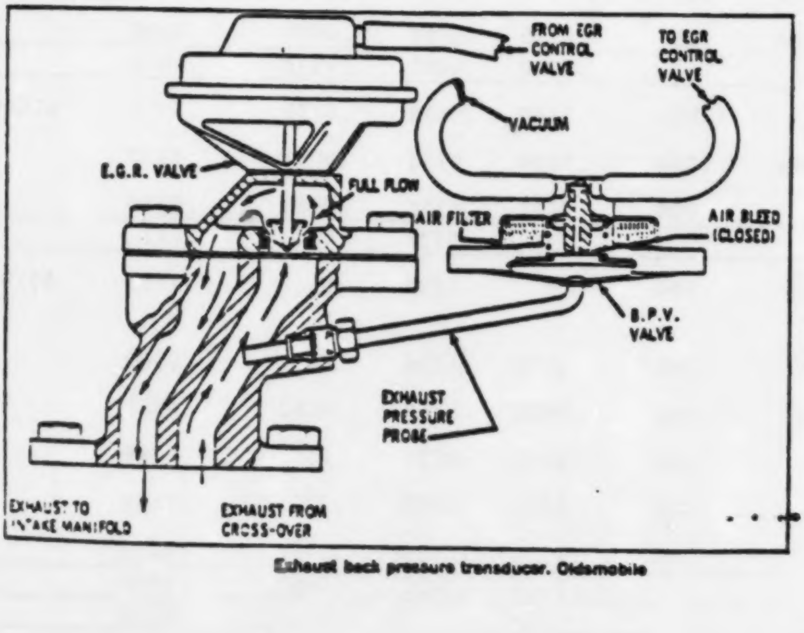
EGR Systems


DIAPHRAGM COVER
VACUUM TUBE CONNECTED TO THERMAL VACUUM SWITCH
SPRING
ACTUATING DIAPHRAGM
VALVE SHAFT
SEAL
VALVE OPEN
VALVE SEAT
VALVE CHAMBER
EXHAUST GAS INLET PORT
TO INTAKE MANIFOLD

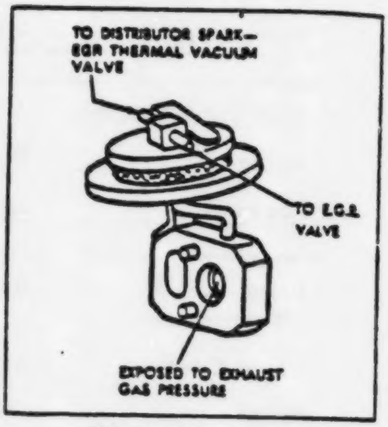
Single diaphragm EGR valve cross section


DIAPHRAGM COVER
SPRING
VACUUM TUBE CONNECTED TO THERMAL VACUUM SWITCH
LARGE DIAMETER PISTON
VACUUM TUBE CONNECTED TO INTAKE MANIFOLD VACUUM
DUAL DIAPHRAGMS
SMALL DIAMETER PISTON
SEAL
VALVE CHAMBER
VALVE SHAFT
VALVE
VALVE SEAT
EXHAUST GAS INLET PORT
TO INTAKE MANIFOLD

Dual diaphragm EGR valve cross section


FROM EGR CONTROL VALVE
TO EGR CONTROL VALVE
VACUUM
E.G.R. VALVE
FULL FLOW
AIR FILTER
AIR BLEED (CLOSED)
B.P.V. VALVE
EXHAUST PRESSURE PROBE
EXHAUST TO INTAKE MANIFOLD
EXHAUST FROM CROSS-OVER

Exhaust back pressure transducer. Oldsmobile


TO DISTRIBUTOR SPARK—EGR THERMAL VACUUM VALVE
TO E.G.R. VALVE
EXPOSED TO EXHAUST GAS PRESSURE

Exhaust back pressure transducer.
Pontiac

EGR Systems

BILL OF MATERIAL
MANUFACTURING COSTS

	Part	Material	Weight	Mat Costs	Labor	Labor Overhead	Mfg Costs	Reference
	EGR Valve Assy	Assem.	.880	-	.1250	.0500	.1750	17053105
								or
Valve Position Actuator	Diaphragm Cover	Steel	.200	.0400	.1250	.0500	.2150	17052364
	Diaphragm Spring	Steel	.100	.0200	.0625	.0250	.1075	$18.05
	Large Dia. Piston	Steel	.090	.0180	.0312	.0125	.0617	
	Diaphragms	Rubber	.050	.0200	.0156	.0062	.0418	.5713
	Small Dia. Piston	Steel	.090	.0180	.0312	.0125	.0617	33% of
	Vac. Tube Conn.	Steel	.100	.0200	.0156	.0062	.0418	Total MC
	Seal	Steel Fibre	.050	.0200	.0156	.0062	.0418	
	Valve Shaft	Steel	.100	.0200	.0312	.0125	.0637	
	Valve	P Metal	.050	.0250	.0156	.0062	.0468	
	Valve Seat	P Metal	.050	.0250	.0156	.0062	.0468	
				.2260	.4841	.1935	.9036	
	EGR Valve Adaptor	Steel	1.320	.2640	.0625	.0250	.3515	416499
	Hoses	Rubber	.050	.0100	.0156	.0062	.0318	
	Gaskets	Asb	.030	.0120	.0156	.0062	.0338	
				.2860	.0937	.0374	.4171	
	Exhaust B.P. Transducer	Assem	.304	-	.1250	.0500	.1750	551083
	Valve Cover	Steel	.064	.0128	.0156	.0062	.0346	
	Filter	Steel	.060	.0120	.0156	.0062	.0338	
	Spring	Steel	.060	.0120	.0156	.0062	.0338	
	Piston	Steel	.020	.0040	.0078	.0031	.0149	
	Probe	Steel	.100	.0200	.0625	.0250	.1075	
				.0608	.2421	.0967	.3996	
	Total						1.7203	

EGR System

BILL OF MATERIAL

Part	Material	Weight	Mat Costs	Labor	Labor Overhead	Mfg Costs	Reference
Vehicle Assem	-	-	-	.2500	.1000	.3500	
Engine Mod.	-	-	-	.0625	.0250	.0875	
Total Vehicle Installation						2.1578	

EGR Systems--Tooling Costs--Amortization Per Part

Part	Economic Volume	1 Year Recurring Tooling	3 Year Non-Recurring Tooling	12 Year Machinery & Equip	12 Year Launching Costs	40 Year Land & Buildings	Amortization Per Piece
EGR Valve Assy	1,000,000	.0200 20,000	.0200 60,000	.0100 120,000	.0010 12,000		.0510
Diaphragm Cover	2,000,000	.0050 10,000	.0050 30,000	.0025 60,000	.0002 6,000		.0127
Diaphragm Spring	5,000,000	.0020 10,000	.0020 30,000	.0010 60,000	.0001 6,000		.0051
Large Dia. Piston	2,000,000	.0025 5,000	.0050 30,000	.0015 36,000	.0002 3,600		.0092
Diaphragms	5,000,000	.0050 25,000	.0040 60,000	.0010 60,000	.0001 6,000		.0101
Small Dia. Piston	2,000,000	.0025 5,000	.0050 30,000	.0015 36,000	.0002 3,600		.0092
Vac. Tube Conn.	4,000,000	.0025 10,000	.0010 12,000	.0005 24,000	.0000 2,400		.0040
Seal	4,000,000	.0025 10,000	.0025 30,000	.0012 60,000	.0001 6,000		.0063
Valve Shaft	4,000,000	.0050 20,000	.0025 30,000	.0025 120,000	.0003 12,000		.0102
Valve	5,000,000	.0040 20,000	.0020 30,000	.0020 120,000	.0002 12,000		.0082
Valve Seat	5,000,000	.0040 20,000	.0020 30,000	.0020 120,000	.0002 12,000		.0082
		.0550	.0510	.0257	.0026		.1343
EGR Vlve Adaptor	1,000,000	.0200 20,000	.0100 30,000	.0100 120,000	.0010 12,000		.0410
Hoses	5,000,000	.0040 20,000	.0017 25,000	.0025 150,000	.0002 15,000		.0084
Gaskets	5,000,000	.0040 20,000	.0017 25,000	.0025 150,000	.0002 15,000		.0084
							.0578

9.2 EGR Systems Tooling Costs--Amortization Per Part (Continued)

Part	Economic Volume	1 Year Recurring Tooling	3 Year Non-Recurring Tooling	12 Year Machinery & Equip	12 Year Launching Costs	40 Year Land & Buildings	Amortization Per Piece
Exh BP Transducer	1,000,000	.0200 20,000	.0100 30,000	.0050 60,000	.0005 6,000		.0355
Valve Cover	2,000,000	.0050 10,000	.0050 30,000	.0025 60,000	.0002 6,000		.0127
Filter	2,000,000	.0050 10,000	.0050 30,000	.0015 36,000	.0002 3,600		.0117
Spring	5,000,000	.0020 10,000	.0020 30,000	.0010 60,000	.0001 6,000		.0051
Piston	2,000,000	.0025 5,000	.0050 30,000	.0015 36,000	.0002 3,600		.0092
							.0742
Vehicle Assem	300,000	.0333 10,000	.0667 60,000	.0167 60,000	.0017 6,000	-	.1183
Engine Mod	300,000	.0667 20,000	.0667 60,000	.0333 120,000	.0033 12,000	-	.1700
Total EGR System on Vehicle							.5546

R&D Estimate: 500,000 for 2 years, or $1.11 per vehicle for a 3-year payback.

EGR System

TOTAL MANUFACTURING COSTS

Part	Mat	Labor	Plant Over-Head	Plant Mfg Costs	Tooling Exp.	Tooling Inv.	.20 MC Corp	.20 MC Corp Profit	Mfg/ Vendor Costs
EGR Valve	.2260	.4841	.1935	.9036	.1060	.0283	.1807	.1807	1.3995
EGR Valve Adaptor	.2640	.0625	.0250	.3515	.0300	.0110	.0703	.0703	.5331
Hoses & Gaskets	.0220	.0312	.0124	.0656	.0113	.0164	.0131	.0131	.1195
BP Transducer	.0608	.2421	.0967	.3996	.0615	.0127	.0799	.0799	.6335
Total Vehicle Mfg Costs	.5728	1.1475			.2088	.0684			2.6857

EGR Systems

RETAIL PRICE EQUIVALENT
AT THE VEHICLE LEVEL

Part	Plant Vendor Costs	R&D	Tools & Equip	Corp. Alloc. .2 VC	Corp. Profit .2 VC	Dealer Markup .4 VC	Vehicle Retail Price Equivalent
EGR Valve	1.3995	1.1111	-	.2799	.2799	.5598	3.6302
EGR Adaptor	.5331	-	-	.1066	.1066	.2132	.9596
Hoses & Gaskets	.1195	-	-	.0239	.0233	.0478	.2151
BP Transducer	.6336	-	-	.1267	.1267	.2534	1.1405
Vehicle Assem	.3500	-	.1183	.0700	.0700	.1400	.7433
Engine Mod	.0875		.1700	.0175	.0175	.0350	.3275
Total Vehicle Price Equivalent							7.0212

EGR System

Cost Comparison to Aftermarket Selling Price

Using the aftermarket discount data and the aftermarket selling price, the following analysis is projected:

	Chilton Aftermarket Selling Price	Reference
EGR Valve	18.05	17052364
Discount 1/4	4.51	or
Discount 1/5	3.61	17053105

The estimated vendor costs are 1.3935 and the vehicle retail price equivalent is 3.6302. This figure includes $1.11 of R&D allocation.

EGR System--Cost Methodology

The weight data were obtained from the Oldsmobile computer printout. The material costs are compiled using the 1977 AMM mill prices.

The labor costs are estimates of production costs using today's technology and the assumed economies of scale. The overhead data are from a company communication. The tooling costs are estimates of expendable tools, fixtures, and dies, as well as estimates of equipment and machinery, to produce the components.

It was assumed that no new buildings were required to produce these parts.

The vehicle assembly costs and the engine changes were included in the costs at the vehicle level.

EGR System--Application of the Systems

Many domestic vehicles have engines equipped with an EGR valve similar to the design used in the estimate. The various applications to engines are numerous, due to the differences in locations in the 4, 6, and 8 cylinder engines. The hoses will vary due to the differences in locations.

IC - CATALYTIC CONVERTERS
HEAVY DUTY GASOLINE TRUCKS

GENERAL

For clarity of presentation, the various catalytic converters have been grouped into two major categories, Monolithic and Pelleted.

The Monolithic ones are:

- Monolithic Oxidation Converters
- Monolithic Reduction Converters
- Monolithic Three-way Converters
- Monolithic Start-up Converters

These are all similar physically, being cylindrical in configuration. They differ primarily only in their catalytic reagents. There can be different sizes, or capacities, in each type.

The Pelleted ones are:

- Pelleted Oxidation Converters
- Pelleted Reduction Converters

Here, also, the physical configurations are similar--a flat pan-shaped enclosure. The noble metals are different, and each can vary in size.

The cost estimations quoted herein were calculated primarily by applying appropriate economy-of-scale factors to those costs estimated in detail and presented in the previous report on cars, EPA - 460/3 - 78 - 002. Costs are in 1977 dollars.

OXIDIZING CATALYTIC CONVERTERS

The oxidation of HC and CO in the exhaust stream can be accomplished at lower temperatures than the thermal reactor by using an appropriate catalyst. The catalyst is contained in a casing which directs the exhaust flow through the catalyst bed and protects the catalyst from mechanical damage. Compared with a thermal reactor, a catalytic converter can be placed further from the engine.

Catalytic converters require the use of fuels with very low levels of lead, phosphorus, and sulphur; small amounts of these contaminants lead to rapid deterioration of catalyst performance.

The catalyst consists of a thin layer of active material deposited on an inert support material. The catalytically active material is usually a noble metal such as platinum or a combination of transition metal oxides.

To obtain effective performance as rapidly as possible after engine start--up, the density of the support material is kept as low as is practical.

There are two basic configurations for the support material in oxidizing catalytic converters:

(1) Pellets of Alumina
(2) Monolithic Honeycombs of Alumina

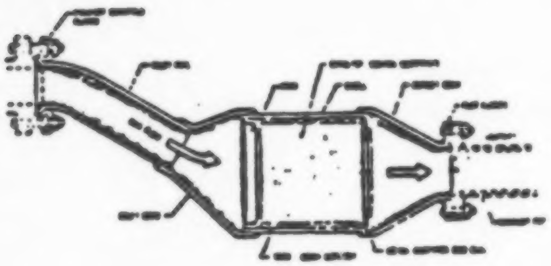
MONOLITHIC CONVERTERS

Monolithic Oxidizing Catalyst

The monolithic oxidizing catalyst converter consists of a noble metal wash coat on a ceramic or paper substrate mounted in an insulated metal container supported by a wire mesh screen. This construction is usually mounted close to the exhaust manifold ahead of the fire wall as an integral part of the exhaust pipe (either the Y-pipe or the straight pipe that connects to the muffler).

Its function is to convert the HC and CO gases to H_2O and CO_2 in the exhaust system.

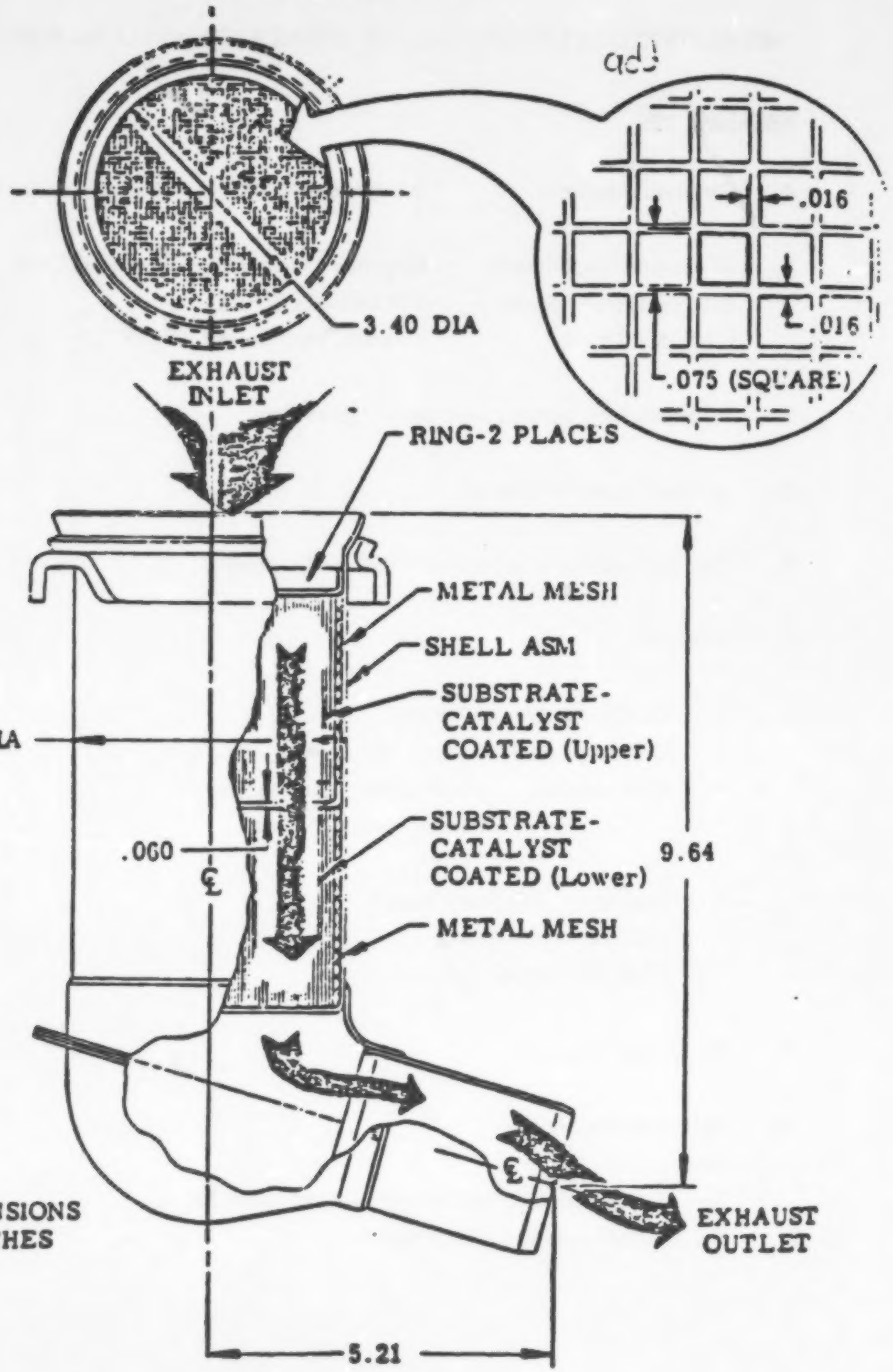
A 63 cubic inch unit is used as a base to develop the detailed cost estimations. Such a unit is used on 6-cylinder, 250 cubic inch California cars. Costs for other sizes can be estimated according to the formulae presente



Ford monolithic converter—cutaway view
(© Ford Motor Co)

MANIFOLD CONVERTER

63 cu. in. substrate volume


adj
.016
.016
.075 (SQUARE)
3.40 DIA
EXHAUST INLET
RING-2 PLACES
METAL MESH
SHELL ASM
SUBSTRATE-CATALYST COATED (Upper)
4.00 DIA
SUBSTRATE-CATALYST COATED (Lower)
.060
℄
9.64
METAL MESH
℄
EXHAUST OUTLET
5.21

NOTE:
ALL DIMENSIONS
ARE IN INCHES

MONOLITHIC OXIDIZING CATALYTIC CONVERTER, 63 CU. IN. SUBSTRATE

Specifications:

A. Catalyst Supplier:

AC Spark Plug Division
1300 N. Dort Highway
Flint, MI 48566

Washcoat and Active Material Applied by:

Engelhard Mineral and Chemical Corp.
529 Delancy Street
Newark, New Jersey 07105

B. Number of converters used per vehicle: One

C. General Type: Oxidation

D. General Location: Attached to exhaust manifold

E. Substrate

1. Configuration: Monolith
2. Construction Technique: Extruded
3. Composition: Major phase - Cordierite
   Minor phase - Mullite

4. Supplier: AC Spark Plug
   1300 N. Dort Highway
   Flint, MI 48556

F. Washcoat: Alumina

G. Active Material:

1. Composition - Platinum and Palladium in 5.2 ratio
2. Total Loading - .029 troy oz.

H. Container:

1-2 See Schematic

3 Volume - 2100 ml

4-6 The container is constructed of steel by forming and welding. The monolith is contained by metal mesh.

7 Canner: AC Spark Plug

8 (a) Insulation: None

(b) Shielding: None

I. Physical Description (of substrate)

1. Dimensions: 2 pieces 3.66" diameter x 3" long
2. Weight: 1.9 lbs. (Modified to 1.3 per Corning Glass data)
3. Volume: 63 cu. in.
4. Total Surface Area (BET): 10,300M^2
5. Approximate Active Surface Area: 8,900M^2

Monolithic Oxidizing Catalyst, 63 cu. in. substrate

BILL OF MATERIAL
MANUFACTURING COSTS
(63 cu. in. volume)

Part	Material	Weight	Mat Costs	Labor	Labor Overhead	Mfg. Costs
Converter Assem	Assem	7.800	-	.68	.27	.95
Shell	409 SS	2.000	1.08	.17	.07	1.32
Ring	409 SS	1.000	.54	.08	.03	.65
Inlet Cone	409 SS	1.000	.54	.08	.03	.65
Outlet Cone	409 SS	1.000	.54	.08	.03	.65
Inlet Pipe	409 SS	1.000	.54	.08	.03	.65
Flanges	409 SS	.250	.14	.04	.02	.20
Mesh	409 SS	.150	.08	.04	.02	.14
Hardware	Steel	.100	.03	.04	.02	.09
Substrate	Ceramic	1.300	6.32	.34	.14	6.80
Washcoat	AL_2O_3		.81	.17	.07	1.05
Sub Total			10.62	1.80	.73	13.10
Platinum	Platin.	.02075 T. oz	3.46	.06	.03	3.55
Paladium	Palad.	.0083 T. oz	.57	.03	.01	.61
Total			14.65	1.89	.77	17.31
Vehicle Assem	-	-	-	.13	.05	.18
Body Modification	-	-	-	.13	.05	.18
Total Vehicle			14.65	2.15	.87	17.67

Monolithic Oxidation Catalyst--Tooling Costs--Amortization Per Piece

(VOLUME AND $ INVESTED EXPRESSED IN THOUSANDS)

Part	Volume	1 Year Recurring Tooling	3 Year Non-Recurring Tooling	12 Year Machinery & Equip	12 Year Launching Costs	40 Year Land & Buildings	Amortization Per Piece
Converter Assem	50	.30 15	.30 45	.08 50.4	.01 5.0	.01 500	.70
Shell	50	.30 15	.30 45	.08 50.4	.01 5.0		.69
Ring	100	.07 7.5	.05 15	.01 16.8	- 1.7		.13
Inlet Cone	50	.15 7.5	.10 15	.03 16.8	.01 1.7		.29
Outlet Cone	50	.15 7.5	.10 15	.02 16.8	- 1.7		.28
Inlet Pipe	50	.15 7.5	.10 15	.03 16.8	- 1.7		.28
Flanges	100	.05 5.0	.04 11	.01 7.0	- 0.8		.10
Mesh	50	.15 7.5	.10 15	.03 16.8	- 1.7		.28
Hardware	250	.01 2.5	.01 8	.01 8.4	- 0.8		.03
Subtotal		1.33	1.10	.31	.03	.01	2.78
Substrate	50	.30 15	.30 45	.13 84	.01 8.4		.74
Washcoat	50	.10 5	.10 15	.05 33.6	.01 3.4		.26
Platinum	50	.10 5	.10 15	.05 33.6	.01 3.4		.26
Paladium	50	.10 5	.10 15	.05 33.6	.01 3.4		.26
Subtotal		.60	.60	.28	.04		1.52
Vehicle Assem	50	.30 15.3	.30 46	.23 136.8	.02 13.7		.85
Body Modification	50	.03 1.5	.03 5	.02 13.7	- 1.4		.08
Total							5.23

Monolithic Oxidization Catalyst, 63 cu. in.

TOTAL MANUFACTURING COSTS

(63 cu. in. vol.)

Part	Mat	Labor	Plant Over-Head	Plant Mfg Costs	Tooling Exp.	Tooling Inv.	.20 MC Corp	.20MC Corp Profit	Mfg/ Vendor Costs
Converter Assem	-	.68	.27	.95	.60	.09	.19	.19	2.02
Converter Can	3.49	.61	.25	4.35	1.83	.23	.87	.87	8.15
Substrate	11.16	.60	.25	12.01	1.20	.32	2.40	2.40	18.33
Total	14.65	1.89	.77	17.31	3.63	.64	3.46	3.46	28.50

Monolithic Oxidation Catalyst, 63 cu. in.

RETAIL PRICE EQUIVALENT AT THE VEHICLE LEVEL

Part	Plant Vendor Costs	R&D	Tools & Equip	Corp .2 VC Alloc	Corp .2 VC Profit	Dealer .4 MC Markup	Vehicle Retail Price Equivalent
Converter Assem	2.02	4.00	-	.46	.40	.80	7.62
Converter Can	8.15	-	-	1.63	1.63	3.26	14.67
Substrate	18.33	-	-	3.67	3.67	7.34	33.01
							55.30
Vehicle Assem	.30	-	.85	.06	.06	.12	1.39
Body Mod.	.30	-	.08	.06	.06	.12	.62
Total Vehicle Price Equivalent							57.31

Monolithic Oxidation Catalyst--63 cu. in. Cost Methodology

The weight data were obtained from the EPA and Chrysler data base. The material costs were computed using 1977 AMM mill prices.

The labor costs are estimates of production costs using today's technology and assumed volume of 50,000 per year.

The tooling costs are estimates of expendable fixtures, dies, and molds. The machinery and equipment are separate estimates based on 1977 costs of new equipment.

Some new building expenditures were included in the estimates since no prior capacity existed to produce the ceramic substrates.

Some modifications to the body structure were included in the estimates of labor and tooling.

FORM A

CALCULATION SHEET FOR PLANT MANUFACTURING COST AND RETAIL PRICE EQUIVALENT OF MONOLITHIC CATALYTIC CONVERTERS

	LOADING (GM/FT^3)				VOLUME (IN.^{3})		TOTAL GRAMS
DATA:		+	1728	×		=	

Pt/Pd Ratio =

(Pt+Pd) Portion =

Pt/Rh Ratio =

(Pt+Rh) Portion =

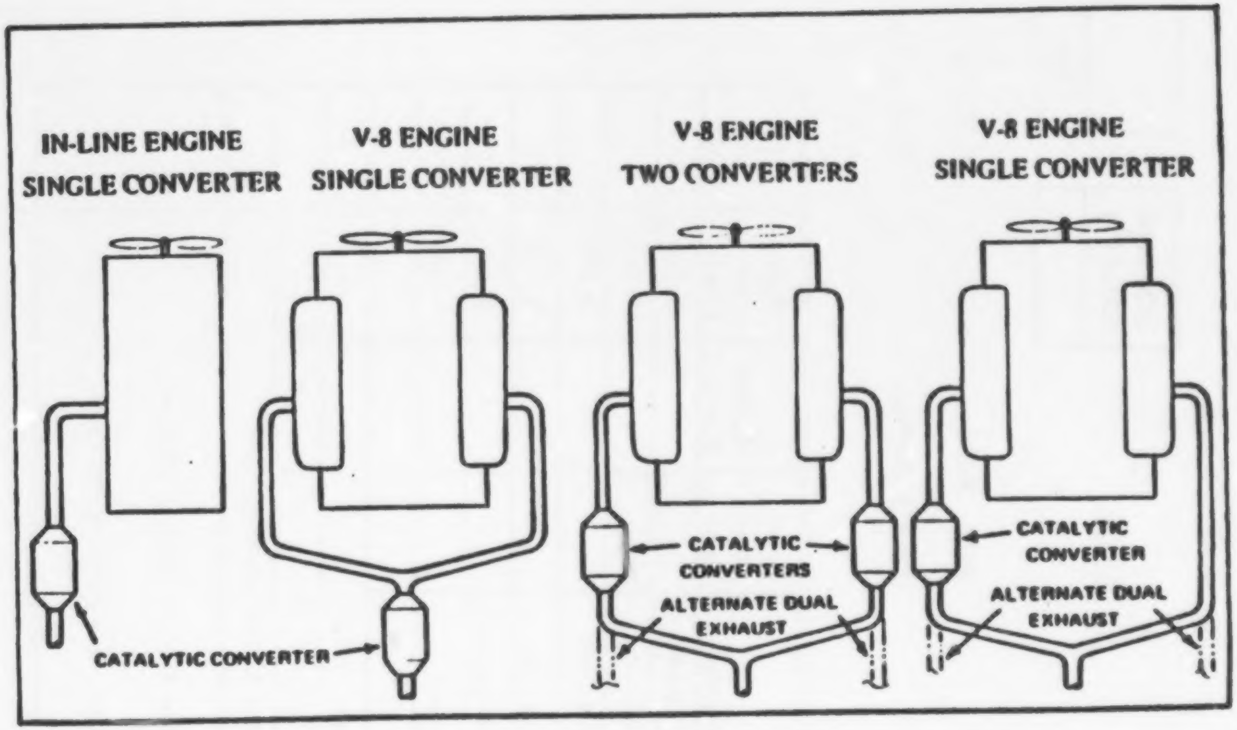
	Material	Pro-portions	Grams Req'd.	Price per Gram	$ per Unit
CATALYTIC COMPONENTS	Platinum			5.369	
	Rhodium			14.628	
	Palladium			2.220	
	Rhenium			1.709	
	Ruthenium			2.009	
	Nickel			.005	
	Total Grams			--	--
	Labor & O.H.		x .14 =		
	Plant Manufacturing Cost				$
STRUCTURAL COMPONENTS	Plant Manufacturing Cost = $4.05 + .144 x volume				$
	TOTAL PLANT MANUFACTURING COST				$

TOTAL PLANT MANUFACTURING COST $ × 2.32 + $13.75 = R.P.E. $

Monolithic Oxidation Catalyst--Application of the Systems

Refer to the enclosed schematic which illustrates the locations by engine type.

TYPICAL INSTALLATIONS CATALYTIC CONVERTER


IN-LINE ENGINE
SINGLE CONVERTER
V-8 ENGINE
SINGLE CONVERTER
V-8 ENGINE
TWO CONVERTERS
V-8 ENGINE
SINGLE CONVERTER
CATALYTIC CONVERTER
CATALYTIC CONVERTERS
ALTERNATE DUAL EXHAUST
CATALYTIC CONVERTER
ALTERNATE DUAL EXHAUST

MONOLITHIC OXIDIZING CATALYTIC CONVERTERS - SIZE GRADUATIONS
FORMULAE FOR MANUFACTURING COST AND RETAIL PRICE
EQUIVALENT ESTIMATIONS OF MONOLITHIC CATALYTIC CONVERTERS

Form A, attached, is, in effect, an equation relating noble metal composition, loading, and volume to manufacturing cost and retail price equivalent.

Form A applies to:

a. Monolithic oxidation catalysts.
b. Monolithic reduction Catalysts.
c. Monolithic 3-way catalysts.
d. Monolithic start catalysts.

Derivation of the Form A equation for plant manufacturing costs.

Catalytic components--plant manufacturing costs.

Grams of each ingredient are precisely defined when proportions, volume, and loading are specified.

Prices are based on 1977 published quotations:

Platinum (Pt)	\$167./Troy oz.
Rhodium (Rh)	\$455./Troy oz.
Palladium (Pd)	\$ 69./Troy oz.
Rhenium (Re)	\$ 53./Troy oz.
Ruthenium (Ru)	\$ 62./Troy oz.
Nickel (Ni)	\$2.23/lb.
Copper (Cu)	\$0.75/lb.

Labor and overhead, \$.14/gram, is used as a constant; taken from the 63 cubic inch converter previously estimated in detail. (See Appendix A for detail calculations)

Structural components--plant manufacturing costs.

The preceding estimate for the 63 cubic inch oxidizing catalytic converter is used as the base for graduations to other sizes.

To conform with the imposed maximums on diameter and length, 6" and 24" respectively, two diameters have been incorporated. For volumes up to 150 cubic inches, a 4" diameter shell is specified: above 150 cubic inches up to 400 cubic inches, a 5.4 inch diameter is specified. (Work sheets appended)

Other variations of these dimensions would have minimal effect on the final costs.

The weights of the individual structural components of the basic 63 cubic inch unit were extrapolated on the geometrical ratios applicable to other volumes. These ratios were (where D = Diameter, L = Length, and V = Volume):

Shell - $(D \times L) + (\frac{D^2}{4})$
Rings - D ; (one per 5" length)
Inlet Cone - D
Outlet Cone - D
Inlet Pipe - D
Flanges - D
Mesh - D x L
Hardware - D
Substrate - V
Wash Coat - V

Material costs per pound were maintained as used in the basic unit.

Labor costs for the components were computed on the generalized relationship that the rate of change of labor input is 60% that of the rate of change of weight, algebraically expressed:

$$\frac{L_2}{L_1} = 1 + 0.6\left(\frac{W_2}{W_1} - 1\right) = 0.4 + 0.6\,\frac{W_2}{W_1}$$

Labor overhead held consistent at 40%.

Plant manufacturing cost is the sum of material cost, labor cost, and labor overhead.

Using the above guides, the plant manufacturing costs for seven sizes were calculated: (Work sheets appended) Results were:

Volume (In^3)	Plant Manufacturing Cost
10	$ 5.42
63 (Basic)	13.15
100	18.25
150	25.68
200	33.31
250	39.87
300	47.42
400	61.48

Applying linear regression, a best-fit line was found.

Plant Manufacturing Cost = $4.05 + ($.144 x Volume)

A graph, appended, of the data points and the best-fit line indicates the error band around the line.

(See Appendix B for details)

Derivation of the Form A equation for converting plant manufacturing to the Retail Price Equivalent.

The equation is:

Retail Price Equivalent = (Plant Manufacturing Cost x 2.52) + $13.75

The cost elements added to convert from plant manufacturing cost to retail price equivalent are:

Plant Manufacturing Cost	Plus	Expense Tooling	$3.63
		Investment Tooling	.64
		Vendor G & A	20% of Mfg. Cost
		Vendor Profit	20% of Mfg. Cost
Equals	Vendor Cost		1.4 (P.M.C.) + $4.27
Vendor Cost	Plus	R & D	4.00
		Vehicle Assembly	1.39
		Body Modification	.62
		Vehicle Corp G & A	20% of Vendor Cost
		Vehicle Corp Profit	20% of Vendor Cost
		Dealer Markup	40% of Vendor Cost
Equals			
Retail Price Equivalent			1.8 (V.C.) + $6.06
			= 1.8 (1.4 M.C.+ 4.23) $6.06
			= 2.52 (M.C.) + $13.75

Monolithic Reduction Catalyst (as a function of volume, noble metal loading and compostion)

Reduction of nitric oxide in the exhaust gas in the presence of carbon monoxide and hydrogen can be accomplished with a suitable catalyst at typical exhaust-gas temperatures.

The catalyst is usually made up of a small mass of active material such as noble metal or a combination of transition and non-transition metals deposited on thermally stable support materials such as alumina. To prevent loss in catalytic activity due to mechanical damage, small spheric pellets or a honeycomb (monolithic structure) have been found the most suitable geometries. The catalyst is contained in a metal casing designed to direct the exhaust flow through the catalyst bed. Self-supporting metallic catalysts are also being developed.

For high conversion efficiency throughout the test cycle, the catalyst must attain its "light-off" temperature* as soon as possible after engine start-up. Considerable development work has, therefore, been done to reduce the density of the support material and increase the surface area of the active components. To maintain high catalytic activity with many of the catalysts being developed, the fuels employed must be low in concentration of various catalyst poisons such as lead, phosphorus, and sulfur.

Because maximum NO_x reduction occurs in a reducing atmosphere, the reducing converter must be placed upstream of the final oxidation catalyst or reactor, and the engine must be operated with a fuel-rich fuel-air mixture.

Same calculation as for oxidizing catalyst, except for loading.

---

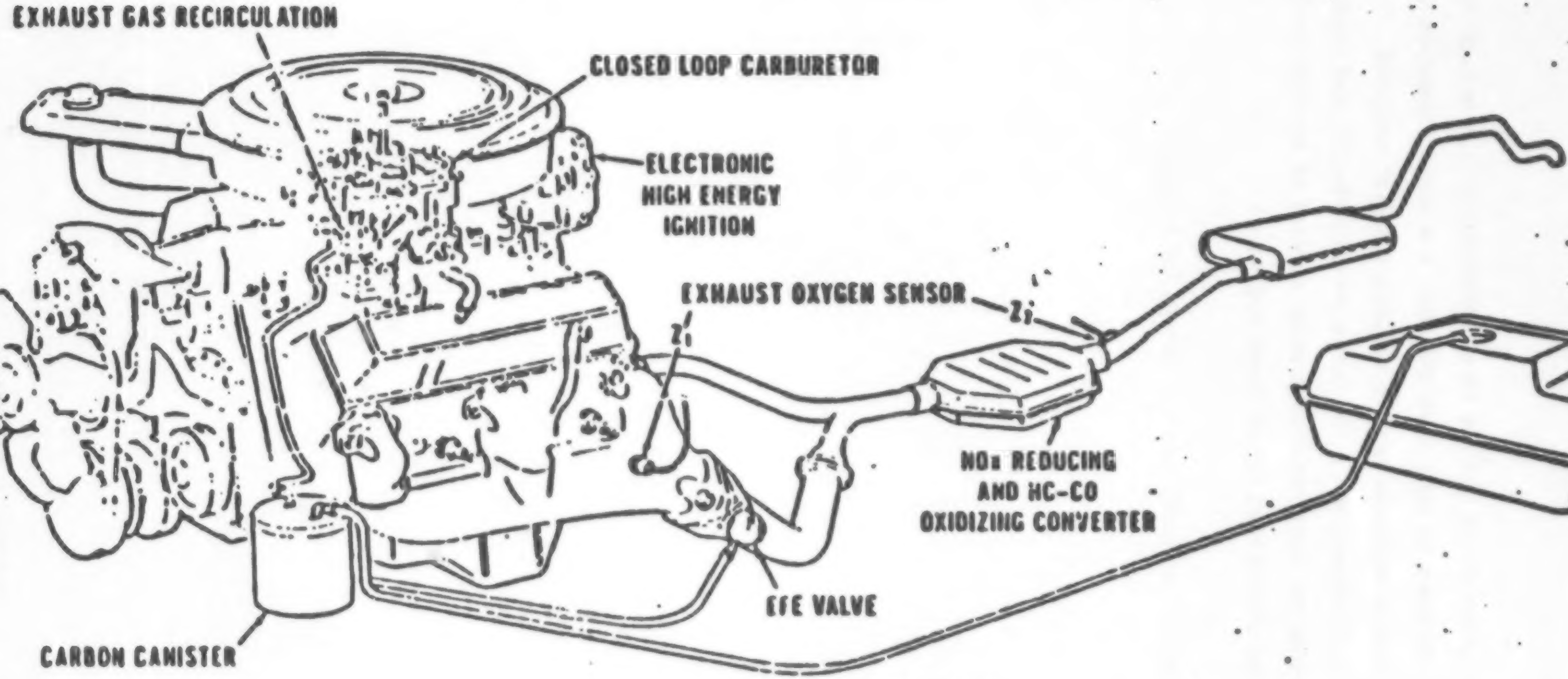
*The temperature at which the catalyst becomes effective.

Monolithic Three-Way Catalyst (as a function of volume, noble metal loading and composition.)

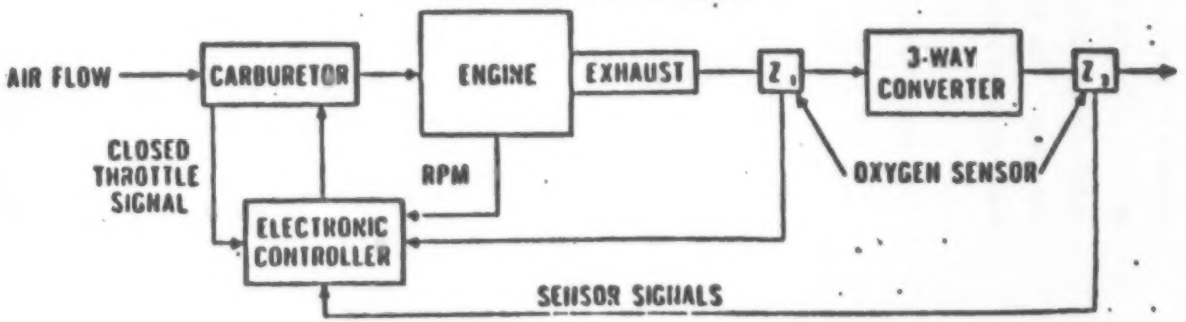
When the exhaust gas composition is close to stoichiometric (just enough air is present in the fuel-air mixture to fully burn the fuel) the simultaneous removal of HC, CO, and NO_x can be achieved with a suitable catalyst material. These catalysts are similar in construction to the noble metal reducing and oxidizing catalysts. The three-way catalyst requires precise control of air-fuel ratio to maintain high conversion efficiencies for all three pollutants.

Same calculation as for oxidizing catalyst except for loading.

3-WAY CATALYST EMISSION CONTROL SYSTEM


EXHAUST GAS RECIRCULATION
CLOSED LOOP CARBURETOR
ELECTRONIC HIGH ENERGY IGNITION
EXHAUST OXYGEN SENSOR
Z_1
Z_1
NOx REDUCING AND HC-CO OXIDIZING CONVERTER
EFE VALVE
CARBON CANISTER

FUNCTIONAL SCHEMATIC


AIR FLOW
CARBURETOR
ENGINE
EXHAUST
Z_1
3-WAY CONVERTER
Z_2
CLOSED THROTTLE SIGNAL
RPM
OXYGEN SENSOR
ELECTRONIC CONTROLLER
SENSOR SIGNALS

Monolithic Start-up Catalyst

The start-up catalyst, or the warm-up catalyst, is designed to provide catalytic conversion during the first two minutes of the engine warm up. It is during this period (quick light off) that major emissions of HC + CO are created. The start catalyst is designed to provide conversion at 400 degrees F or less while the main catalyst is still heating up. These catalysts were provided for California cars where standard formula HC + CO + NOx was more stringent than the Federal standard.

Same calculation as for oxidizing catalysts, except for loading.

WARM-UP CATALYST DESCRIPTION*

AMC (California) used on 304 and 360 cu. in. engines

Catalyst Features, such as:

a) Catalyst supplier and address: Engelhard Industries Division
(Sole supplier)
430 Mountain Avenue
Murray Hill, New Jersey 07974

b) Number of catalysts used per vehicle: 1 for 6 cyl, 1 for V-8 Hornet/Pacer
2 for V-8 Matador

c) General Type: Oxidation

d) General Location: At exhaust manifold

e) Substrate:
   (i) Configuration - Monolithic, segmented
   (ii) Construction Technique - Extruded
   (iii) Composition - Corderite
   (iv) Supplier and Address: Corning Glass Works Division
   (Sole supplier)
   Corning, New York

f) Washcoat: Stabilized activated coating proprietory to manufacturer

g) Active Material:
   (i) Composition of active constituents - Pt/Pd - 2/1
   (ii) Total active material loading (gms. or Troy oz.) - 50 gm/ft.^{3}

h) Container:
   (i) Configuration - Cylindrical
   (ii) Dimensions - 3.87 dia. x 6.6 overall length

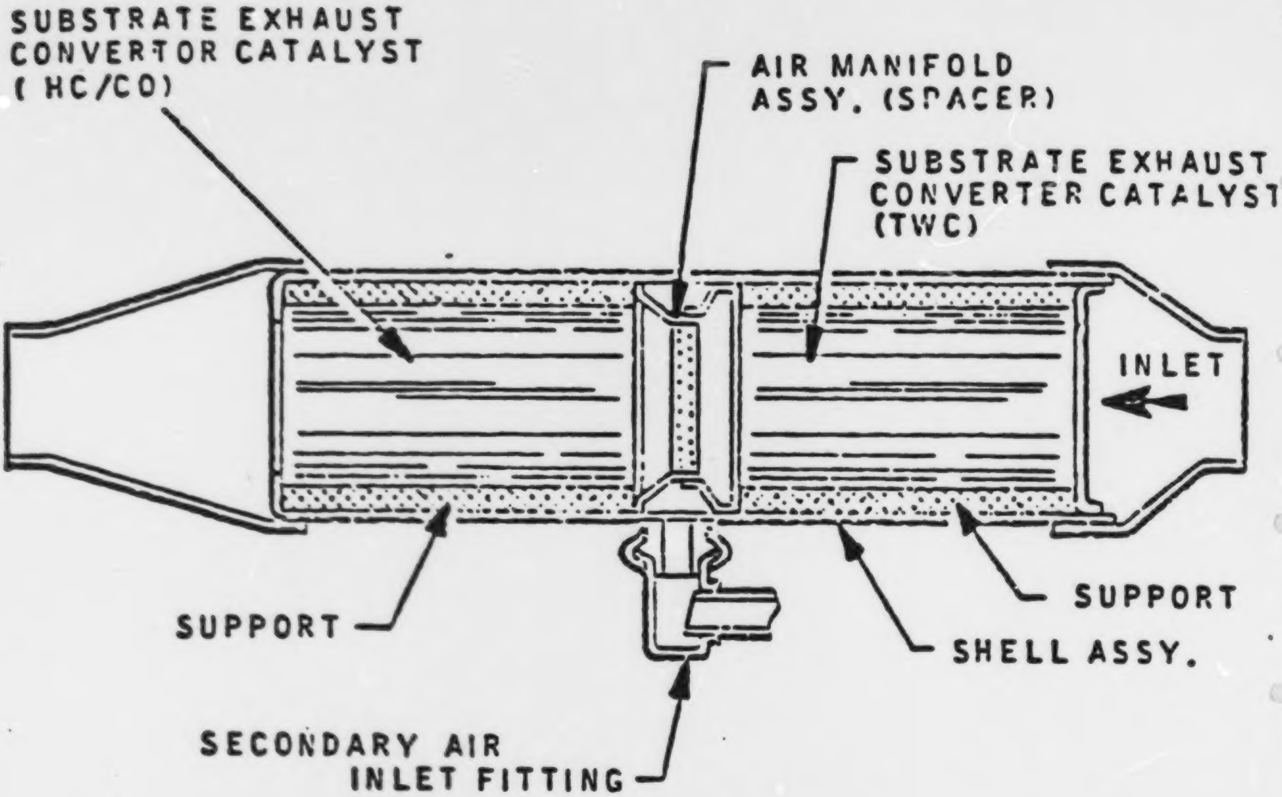
   (iii) Volume - 48.8 In.^{3}
   (iv) Materials used - 409 Stainless .054" min.
   (v) Technique of containment & restraint - Compliant wire mesh
   Mounting rings
   (vi) Canner: Maremont Corporation
   (Sole supplier)
   250 East Kehoe Boulevard
   Carol Stream, Illinois 60187
   (viii) Insulation and shielding (catalyst and/or vehicles) - None

i) Physical Description:

- (i) Dimensions: 2 pieces, 3.66 dia. x 1.25; (3.31 EFF dia.)
- (ii) Weight (lbs): Catalyst only, 0.61 lbs. (Modified to .53 lbs. per corning Glass Data)
- (iii) Volume: EFF Catalyst 21.5 In.^{3}, Total - 26.3 In.
- (iv) Active surface area (BET): Proprietory to manufacturer

j) Catalyst Assembly Part Number: To be supplied

TW.C Catalytic Converter Assembly


SUBSTRATE EXHAUST CONVERTOR CATALYST (HC/CO)
AIR MANIFOLD ASSY. (SPACER)
SUBSTRATE EXHAUST CONVERTER CATALYST (TWC)
INLET
SUPPORT
SUPPORT
SHELL ASSY.
SECONDARY AIR INLET FITTING

PELLETED CONVERTERS
PELLETED OXIDIZING CATALYST

The pelleted oxidizing catalyst converter consists of alumina pellets which have wash-coated with noble metals packed in a metal container which is in turn encased in an insulated outer metal shell.

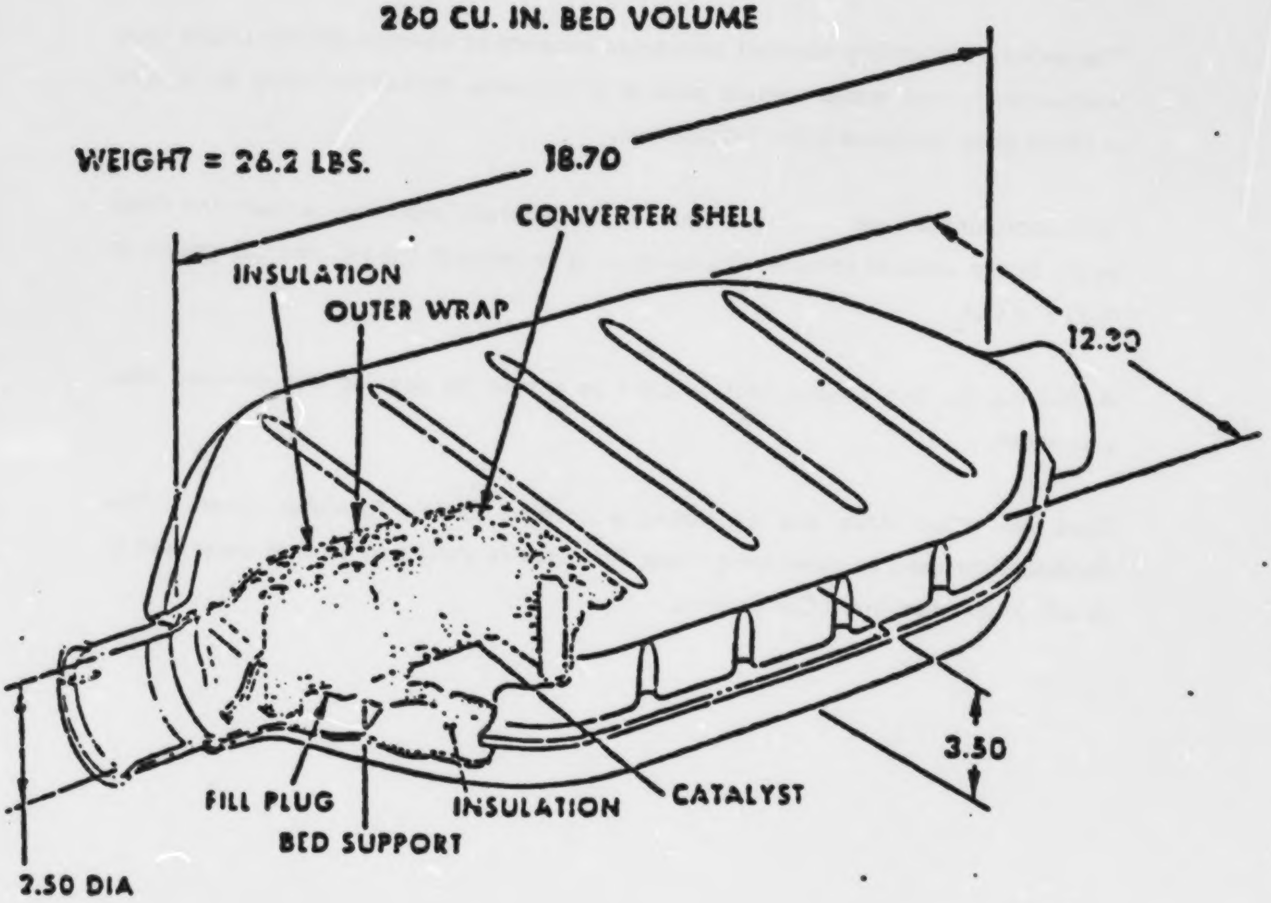
This construction, resembling a flat pan, is generally mounted beneath the floor board in the exhaust stream. Its function is to convert the HC and CO gasses to H_2O and CO_2.

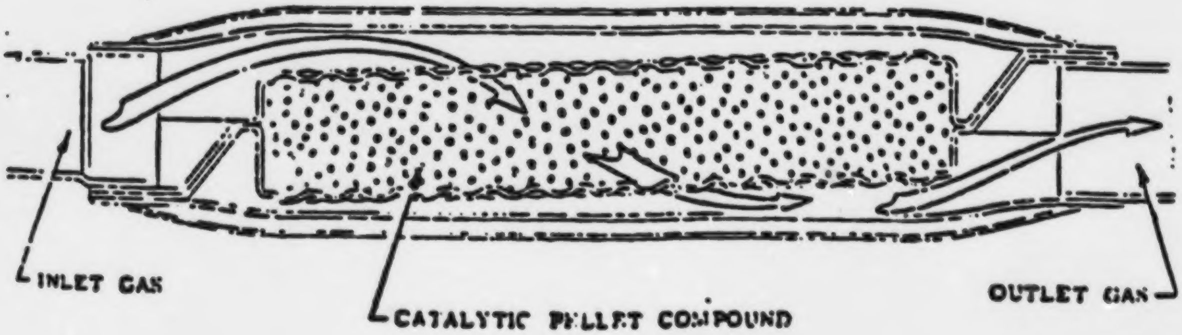
A 260 cu. in. bed volume unit is used as a base to develop the detailed cost estimates.

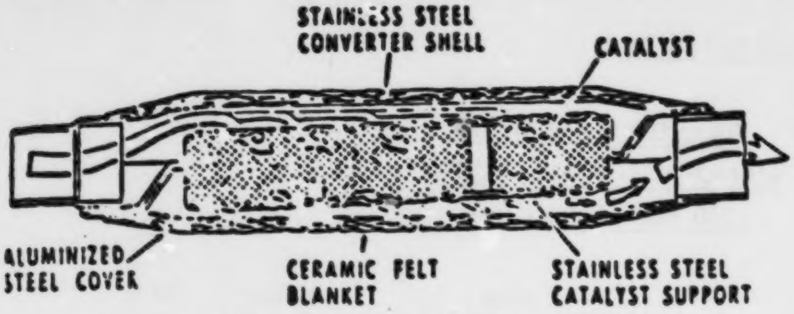
Cost for other sizes are estimated according to the formulae given. The methodology used in developing these formulae is analagous to that described in detail under Monolithic Converters.

UNDERFLOOR CONVERTER - FULL FLOW

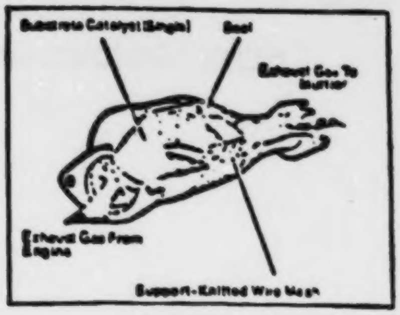
260 CU. IN. BED VOLUME


WEIGHT = 26.2 LBS.
18.70
CONVERTER SHELL
INSULATION
OUTER WRAP
12.30
3.50
FILL PLUG
INSULATION
CATALYST
BED SUPPORT
2.50 DIA

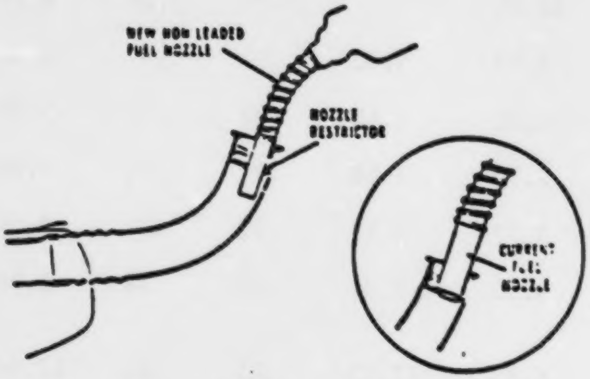

INLET GAS
CATALYTIC PELLET COMPOUND
OUTLET GAS


STAINLESS STEEL CONVERTER SHELL
CATALYST
ALUMINIZED STEEL COVER
CERAMIC FELT BLANKET
STAINLESS STEEL CATALYST SUPPORT

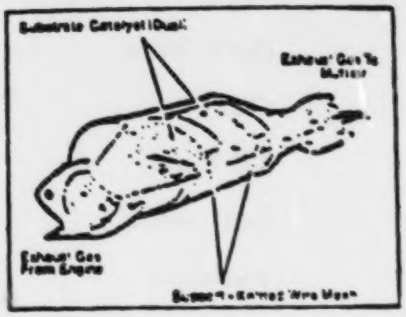
American Motors & General Motors catalytic converter


Substrate Catalyst (Single)
Seal
Exhaust Gas To Muffler
Exhaust Gas From Engine
Support-Knitted Wire Mesh

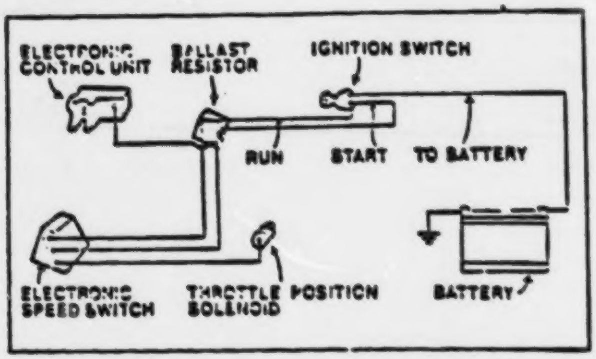
Ford catalytic converter
with single substrate catalyst


NEW NON LEADED FUEL NOZZLE
NOZZLE RESTRICTOR
CURRENT FUEL NOZZLE

Fuel tank filler safety neck for all vehicles equipped
with catalytic converters (Typical)


Substrate Catalyst (Dual)
Exhaust Gas To Muffler
Exhaust Gas From Engine
Support-Knitted Wire Mesh

Ford catalytic converter
with dual substrate catalyst


ELECTRONIC CONTROL UNIT
BALLAST RESISTOR
IGNITION SWITCH
RUN
START
TO BATTERY
ELECTRONIC SPEED SWITCH
THROTTLE POSITION SOLENOID
BATTERY

Chrysler Corp. catalyst protection system for all vehicles
equipped with catalytic converters

Reproduced from
best available copy.

Pelleted Oxidation--Catalyst 260 cu. in.

BILL OF MATERIAL
MANUFACTURING COSTS
(260 cu. in. volume)

Part	Material	Weight	Mat Costs	Labor	Labor Overhead	Mfg Costs
Converter Assembly	Assem	26.20	-	3.10	1.24	4.34
Outer Wrap	409 SS	8.00	5.36	.92	.37	6.65
Shell	409 SS	4.00	2.68	.92	.37	3.97
I/O Pipes	409 SS	2.50	1.68	.27	.11	2.06
Bed Support	409 SS	3.77	2.53	.92	.37	3.82
Insulation	Fibre Glass	1.50	2.01	.05	.02	2.08
Pellets	Alumina PT	6.43	12.79	.05	.02	12.86
Total			27.05	6.23	2.50	35.78
Vehicle Assembly	-	-	-	.34	.14	.48
Body Modification	-	-	-	.17	.07	.24
Total Vehicle			27.05	6.74	2.71	36.50

Pelleted Oxidation Catalyst--Tooling Costs--Amortization Per Piece

(Volumes and Investment $ Expressed in 1,000s)

Part	Economic Volume	1 Year Recurring Tooling	3 Year Non-Recurring Tooling	12 Year Machinery & Equip	12 Year Launching Costs	40 Year Land & Buildings	Amortization Per Piece
Converter Assem	50	1.75 40	3.49 540	2.69 1,600	.27 160	1.62 3,200	9.82
Outer Wrap	50	1.75 90	3.49 540	2.69 1,600	.27 160		8.20
Shell	50	1.75 90	1.75 270	1.35 800	.14 80		4.99
I/O Pipes	100	.17 18	.17 54	.13 160	.01 16		.48
Bed Support	50	1.75 90	3.49 540	2.69 1,600	.27 160		8.20
Insulation	50	.35 18	.35 54	.40 240	.04 24		1.14
Pellets	50	.35 18	.35 54	.65 400	.07 40		1.42
Total Converter		7.87	13.09	10.60	1.07	1.62	34.25
Vehicle Assem	50	.30 15	.09 15	.07 46	.01 5		.47
Body Modification	50	.49 13	.49 37	.05 17	.05 2		1.08
Total Vehicle							35.80

Pelleted Oxidation Catalyst--260 cu. in.

TOTAL MANUFACTURING COSTS

(260 cu. in. volume)

Part	Mat	Labor	Plant Over-Head	Plant Mfg. Costs	Tooling Exp.	Tooling Inv.	.20 MC Corp	.20 MC Corp Profit	Mfg./ Vendor Costs
Converter Assembly	-	3.10	1.24	4.34	5.24	4.58	.87	.87	15.90
Converter Can	14.26	3.08	1.24	18.58	15.02	7.99	3.72	3.72	49.03
Pellets	12.79	.05	.02	12.86	.70	.72	2.57	2.57	19.42
Total	27.05	6.23	2.50	35.78	20.96	13.29	7.16	7.16	84.35

Pelleted Oxidation Catalyst--260 cu. in.

RETAIL PRICE EQUIVALENT
AT THE VEHICLE LEVEL

(260 cu. in. volume)

Part	Plant Vendor Costs	R&D	Tools & Equip	Corp .2 VC Alloc	Corp .2 VC Profit	Dealer .4 VC Markup	Vehicle Retail Price Equivalent
Converter	84.35	1.60	-	16.87	16.87	33.74	153.43
Vehicle Assembly	.48	-	.47	.10	.10	.20	1.35
Body Model	.24	-	1.08	.05	.05	.10	1.52
Total Vehicle Price Equivalent	85.07	1.60	1.55	17.02	17.02	34.04	156.30

PELLETED OXIDATION CATALYST

Cost Methodology

The weight data was obtained from the reference sketch. The pellet weight was also obtained from the sketch. The component weights are estimated by proportional methods.

The labor costs are estimates based on knowledge of the actual plant processes and manning. The economy of scale was established using the General Motors Milwaukee plant as the model.

The tooling and equipment costs are estimates using the General Motors plant as the reference.

The vehicle assembly costs and the body changes are added to the converter costs at the vehicle level.

PELLETED CATALYTIC CONVERTERS - SIZE GRADUATIONS

SIZE GRADATION CALCULATIONS

The configuration is regarded as two rectangular boxes, one centrally located within the other. The outer box is the housing and the inner is the catalyst.

From the referenced sketch, these dimensions for the 260 cubic inch converter are used as basic:

	Height	Width	Length	Area	Volume
Housing	3.5	12.3	18.7	677	-
Catalyst	1.9	10.5	13.0	362	260

In graduating the dimensions to accommodate varying volumes, the catalyst height is held constant (to give maximum cross-flow contact and also to fit tail pipe). Length and width of catalyst are held in the same proportion, 13.0/10.5.

The housing length is constantly 5.7 greater than the catalyst length; the width differential is held at 1.8.

PELLETED CATALYTIC CONVERTERS - SIZE GRADUATIONS

FORMULAE FOR MANUFACTURING COST AND RETAIL PRICE EQUIVALENT ESTIMATIONS FOR PELLETED CATALYTIC CONVERTERS

Form B gives the equation relating noble metal composition, loading, and volume to plant manufacturing cost and retail price equivalent.

It applies to:

a. Pelleted oxidation catalysts.

b. Pelleted reduction catalysts.

The calculations are based on extrapolation of the values given in the detailed estimate made on the 260 cubic inch under-floor oxidation catalyst.

The noble metal prices and the overall logic employed are the same as presented in the section on monolithic catalysts.

Work sheets are attached.

FORM B

CALCULATION SHEET FOR PLANT MANUFACTURING COST AND RETAIL PRICE EQUIVALENT PELLETED CATALYSTS

DATA:

LOADING (GM/FT^3)				VOLUME (IN.^{3})		TOTAL GRAMS
	+	1728	x		=	

Pt/Pd Ratio =

(Pt + Pd) Portion =

Pt/Rh Ratio =

(Pt + Rh) Portion =

	Material	Pro-portions	Grams Req'd	Price per Gram	$ per Unit
CATALYTIC COMPONENTS	Platinum			5.369	
	Rhodium			14.628	
	Palladium			2.220	
	Renium			1.709	
	Ruthenium			2.009	
	Nickel			.005	
	Total Grams			--	--
	Labor & O.H.		x .12 =		
	Plant Manufacturing Cost				$
STRUCTURAL COMPONENTS	Plant Manufacturing Cost = $7.97 (.057 x volume)				$
	TOTAL PLANT MANUFACTURING COST				$

TOTAL PLANT MANUFACTURING COST						R.P.E
$	x	2.52	+	$7.466	=	$

PELLETED CATALYTIC CONVERTERS

DERIVATION OF THE FORM B EQUATION FOR MANUFACTURING COSTS

Catalytic Components

Same as described under Monolithic Oxidizing Converters.

Structural Components

The preceding estimate for the 260 cu. in. converter is used as the base for graduations to other sizes.

Part weights were graduated by the appropriated geometrical parameters. Material costs per pound held constant.

Labor costs graduated at 60% of the weight graduation. Overhead constant at 40% of labor.

Manufacturing costs on 5 sizes were calculated, and on linear regression, best fit, equation was found:

Mfg. Cost, Structural Comps. = (\$.057 x vol.) + \$7.97

PELLETED CATALYSTS

DETERMINATION OF THE FORM B EQUATION FOR ESTIMATING THE RETAIL PRICE EQUIVALENT

The following costs must be added to plant manufacturing cost to get the vendor cost.

Expense Tooling	20.96
Investment Tooling	13.29
Vendor G & A	20% of Plant Manufacturing Cost
Vendor Profit	20% of Plant Manufacturing Cost

Vendor Cost = 1.4 (Manufacturing Cost) + 34.25

To the vendor cost the following must be added to get Retail Price Equivalent.

R & D	$1.60
Vehicle Assembly	1.35
Body Modification	1.52
Vehicle Corp. G & A	20% of Vendor Cost
Vehicle Corp. Profit	20% of Vendor Cost
Dealer Markup	40% of Vendor Cost

$$\begin{aligned}\text{Retail Price Equivalent} &= 1.8\,(\text{Vendor Cost}) + 4.47\\ &= 1.8\left[1.4\,(\text{M.C.}) + 34.25\right] + 4.47\\ &= 2.52\,(\text{Plant Manufacturing Cost}) + 66.12\end{aligned}$$

PELLETED CATALYSTS--DIMENSIONS

CATALYSTS							HOUSING				
Vol. (in.^{3})	Hgt. (in.)	Wdth. (in.)	Lgth. (in.)	Area (in.^{2})	Area Ratio	Vol. Ratio	Hgt. (in.)	Wdth. (in.)	Lgth. (in.)	Area (in.^{2})	Area Ratio
260	1.9	10.5	13.0	362	1.00	1.00	3.5	12.3	18.7	677	1.00
320	1.9	11.6	14.4	433	1.20	1.23	3.5	13.4	20.1	773	1.14
400	1.9	13.0	16.1	530	1.46	1.54	3.5	14.8	21.8	901	1.33

Appendix A

FORMULAE FOR CALCULATION OF THE COST PER GRAM OF CATALYTIC COMPOUNDS

Conversion Factors - Weight

The material prices are typically quoted in varying units of weight. Herewith is a list of factors by which to convert each to grams.

Avoirdupois pounds x 453.5924 = grams
Avoirdupois ounces x 28.3495 = grams
Troy pounds x 373.248 = grams
Troy ounces x 31.104 = grams

Conversion Factors - Volume

Cubic feet x 1728 = cubic inches
Square feet x 144 = square inches

Cost Per Gram of a Composition of Materials (Exact Method)

To calculate the compound cost in dollars per gram, use the following format:

	Quoted Price		Conversion to $/Gram		Pro-Portion in	Compound
Material	$	Unit	Conv. Factor	$/Gram	Compound	$/Gram
A-1	B	C	D	E	F	H
A-2						
A-3						
Etc.						
Total Compound					G 1.00	J

A-1; A-2, Etc. - List ingredients
B & C - Quoted $ and units in which quoted
D - Appropriate conversion factor from 1.1
E - Divide B by D
F - List proportion as decimals (10% = 0.10)
G - Sum of column F must equal 1.000
H - Multiply F by E
J - Sum of column H equals compound cost per gram

Example 1

What is the cost per gram of a compound which contains 2% rhemium; 0.4% ruthenium; 3% nickel; and in which the platinum-to-rhodium ratio is 25:1?

Solution: Rhenium = .020
Ruthenium = .004
Nickel = .030

SUBTOTAL = .054

Remainder = 1.000 - .054 = .946

Platinum $\frac{25}{25+1} \times .946 = .910$

Rhodium $\frac{1}{25+1} \times .946 = .036$

TOTAL 1.000

Material	Quoted Price $	Unit	Conversion to $/Gram Factor	$/Gram	Pro-Portion	Compound $/Gram
Platinum	167.00	T. oz.	31.104	5.369	.910	4.886
Rhodium	455.00	T. oz.	31.104	14.628	.036	.527
Rhenium	775.00	Av. lb.	453.5924	1.709	.020	.034
Nickel	2.23	Av. lb.	453.5924	.005	.030	-
Total Compound					1.000	5.447

Cost per Gram of a Composition of Substrate Materials (Approximation Method)

This short-cut method, within the proportion limits proscribed, will deviate no more than 2% from the exact method described above.

Procedure

1. Calculate the cost per gram as if platinum and rhodium were the only ingredients (Pt + Rh = 100%).
2. Multiply this by the proportion represented by the sum of platinum and rhodium.
3. Add to this the product of the remaining proportion times $.67.

Example 2 (Approximate method)

What is the cost per gram of a compound which contains 2% rhenium; 0.4% ruthenium; 3% nickel; and in which the platinum-to-rhodium ratio is 25:1?

1.

Platinum	25 parts	x $ 5.369 =	$134.225
Rhodium	1 part	x 14.628 =	14.628
Totals	26 parts		$148.853

Cost/gram of mix $\frac{148.853}{26}$ = $5.725

2.

Platinum	91.0%
Rhodium	3.6%
SUM	94.6%

.946 x $5.725 = $5.416

3. (1.000 - .946) x $.67 = $.036

4. $5.416 + $.036 = $5.452 (answer)
(Compare with $5.447 gotten by Exact Method, Example 1.)

Discussion

The short-cut method is made feasible because of two factors:

a) Platinum and rhodium constitute 84.5% or more of the mixture, and
b) The unit price of these is much geater than of the other constituents.

Typical Extreme Calculation

Platinum to Rhodium = 2:1 (upper cost ratio)

Platinum & Rhodium = 84.5% (lower limit)
Rhenium = 5.0% (upper limit)
Ruthenium = .05% (upper limit)
Nickel = 10.0% (upper limit)
100.0%

Platinum	$5.369 x 2/3 x .845	= $3.025
Rhodium	14.628 x 1/3 x .845	= 4.120
	Subtotal	$7.145
Rhenium	1.709 x .050	= .085
Ruthenium	2.009 x .005	= .010
Nickel	.005 x .100	= .001
		$7.241

Note that the last three ingredients which represented 15.5% of the total weight added only $.096 to the subtotal cost of Platinum and Rhodium.

The short-cut formula substitutes 15.5% x $.67 = $.104 for the calculated $.096, creating an error of $.008, which is only 0.11% of the total.

CALCULATION OF THE WEIGHT OF CATALYTIC COMPOUND USED PER CONVERTER

Volume used is expressed in cubic inches.

Loading is spoken of in grams per cubic foot. For ease of calculation this is converted to grams per cubic inch.

$$1 \text{ gram/ft}^3 \times 1/1728 = .0005787 \text{ gm/in}^3$$

Total weight equals volume times loading.

$$\text{weight (grams)} = \text{volume (in}^3) \times \text{loading (gm/ft}^3) \div 1728$$

The matrix following gives grams required for various combination of volume and loading.

GRAMS OF COMPOUND REQUIRED FOR VARIOUS VOLUMES AND LOADINGS

LOADING (Gm/Ft^3)

	1	5	10	15	20	30	40	50	60	70
1	.00058	.00289	.00579	.00868	.01157	.01736	.02315	.02894	.03472	.04051
10	.00579	.029	.058	.087	.116	.174	.231	.289	.347	.405
20	.01157	.058	.116	.174	.231	.347	.463	.579	.694	.810
50	.02894	.145	.289	.434	.579	.868	1.16	1.45	1.74	2.03
100	.05787	.289	.579	.868	1.16	1.74	2.31	2.89	3.47	4.05
150	.08681	.434	.868	1.30	1.74	2.60	3.47	4.34	5.21	6.08
200	.11574	.579	1.16	1.74	2.32	3.47	4.63	5.79	6.94	8.10
250	.14468	.723	1.45	2.17	2.89	4.34	5.79	7.23	8.68	10.13
300	.17361	.868	1.74	2.60	3.47	5.21	6.94	8.68	10.42	12.15
350	.20255	1.01	2.03	3.04	4.05	6.08	8.10	10.13	12.15	14.18
400	.23148	1.16	2.32	3.47	4.63	6.94	9.26	11.57	13.89	16.20

Grams required = Loading (gm/ft^3) x Volume (in^3) ÷ 1728

CALCULATION OF THE COST OF CATALYTIC COMPOUND PER CONVERTER

Cost per converter equals grams required times the cost per gram of the compound.

For purposes of ready reference, a table is presented giving substrate compound costs at selected values of platinum-rhodium ratio, grams required and total platinum-rhodium content.

In this table the following material prices are used:

Platinum	$ 5.369/gm =	$167/Troy oz.
Rhodium	14.628/gm =	455/Troy oz.
Rhenium	1.709/gm =	53/Troy oz.
Ruthenium	2.009/gm =	62/Troy oz.
Nickel	.005/gm =	2.23/av. lb.

Intermediate values may be interpolated, or calculated directly.

Equation for calculating cost of substrate material per converter.

$$\text{COST} = (Pp + Pr)\ \frac{167Pp + 455Pr}{31.104} + \left[1 - (Pp + Pr)\right]\ .67\ \frac{V\,L}{1728}$$

$$\text{when } (Pp + Pr) \geq .845$$

where Pp = Percent Platinum ÷ 100

Pr = Percent Rhodium ÷ 100

V = Volume in cubic inches

L = Loading in grams per cubic foot

COST OF SUBSTRATE MATERIAL PER CONVERTER

% Platinum + % Rhodium = 100%
(See Note 3 if 100%)

Line	Total Grams Substrate Required (Note 1)	Ratio Platinum to Rhodium and Cost Per Gram (Note 2) 2:1 $ 8.455	5:1 $ 6.912	7:1 $ 6.526	9:1 $ 6.295	11:1 $ 6.141	19:1 $ 5.832	25:1 $ 5.725	30:1 $ 5.668
1	.029	$ .25	$ .20	$ .19	$ .18	$ .18	$ .17	$ .17	$ .16
2	.058	.49	.40	.38	.37	.36	.34	.33	.33
3	.116	.98	.80	.76	.73	.71	.68	.66	.66
4	.174	1.47	1.20	1.14	1.10	1.07	1.01	1.00	.99
5	.289	2.44	2.00	1.89	1.82	1.77	1.69	1.65	1.64
6	.579	4.90	4.00	3.78	3.64	3.56	3.38	3.31	3.28
7	1.16	9.81	8.02	7.57	7.30	7.12	6.77	6.64	6.57
8	1.74	14.71	12.03	11.36	10.95	10.69	10.15	9.96	9.86
9	2.31	19.53	15.97	15.08	14.54	14.19	13.47	13.22	13.09
10	3.47	29.34	23.98	22.65	21.84	21.31	20.24	19.87	19.67
11	4.05	34.24	27.99	26.43	25.49	24.87	23.62	23.19	22.96
12	5.21	44.05	36.01	34.00	32.80	31.99	30.38	29.83	29.53
13	6.08	51.41	42.02	39.68	38.27	37.34	35.46	34.81	34.46
14	6.94	58.68	47.97	45.29	43.69	42.62	40.47	39.73	39.34
15	7.23	61.13	49.97	47.18	45.51	44.40	42.17	41.39	40.98
16	8.10	68.49	55.99	52.86	50.99	49.74	47.24	46.37	45.91
17	9.26	78.29	64.01	60.43	58.29	56.87	54.00	53.01	52.49
18	10.13	85.65	70.02	66.11	63.77	62.21	59.08	57.99	57.42
19	11.57	97.82	79.97	75.51	72.83	71.05	67.48	66.24	65.58
20	12.15	102.73	83.98	79.29	76.48	74.61	70.86	69.56	68.87
21	13.89	117.44	96.01	90.65	87.44	85.30	81.01	79.52	78.73
22	14.18	119.89	98.01	92.54	89.26	87.08	82.07	81.18	80.37
23	16.20	136.97	111.97	105.72	101.98	99.48	94.48	92.75	91.82

Note 1: Determine grams required from the table or formula below it. Locate nearest line (or interpolate between two lines) and read $ in appropriate ratio column.

Note 2: Cost per gram calculated at Platinum $167/Troy oz. = $5.369/gram and Rhodium $455/Troy oz. = $14.628/gram.

Note 3: When Rhenium, Ruthenium of Nickel are also included in the compound, multiply the value from the table by the combined percentages of Platinum and Rhodium; add to this the remaining percentage times $.67 times total grams required.

NOBLE METAL PRICES

Metal	Price per Troy Ounce* Wholesale	Price per Troy Ounce* Retail
Platinum	$162	$172
Iridium	300	310
Rhodium	400	410
Paladium	60	65
Ruthenium	60	65

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*Troy Ounce = 31.1035 grams

Source: Matthey-Bishop, Inc.

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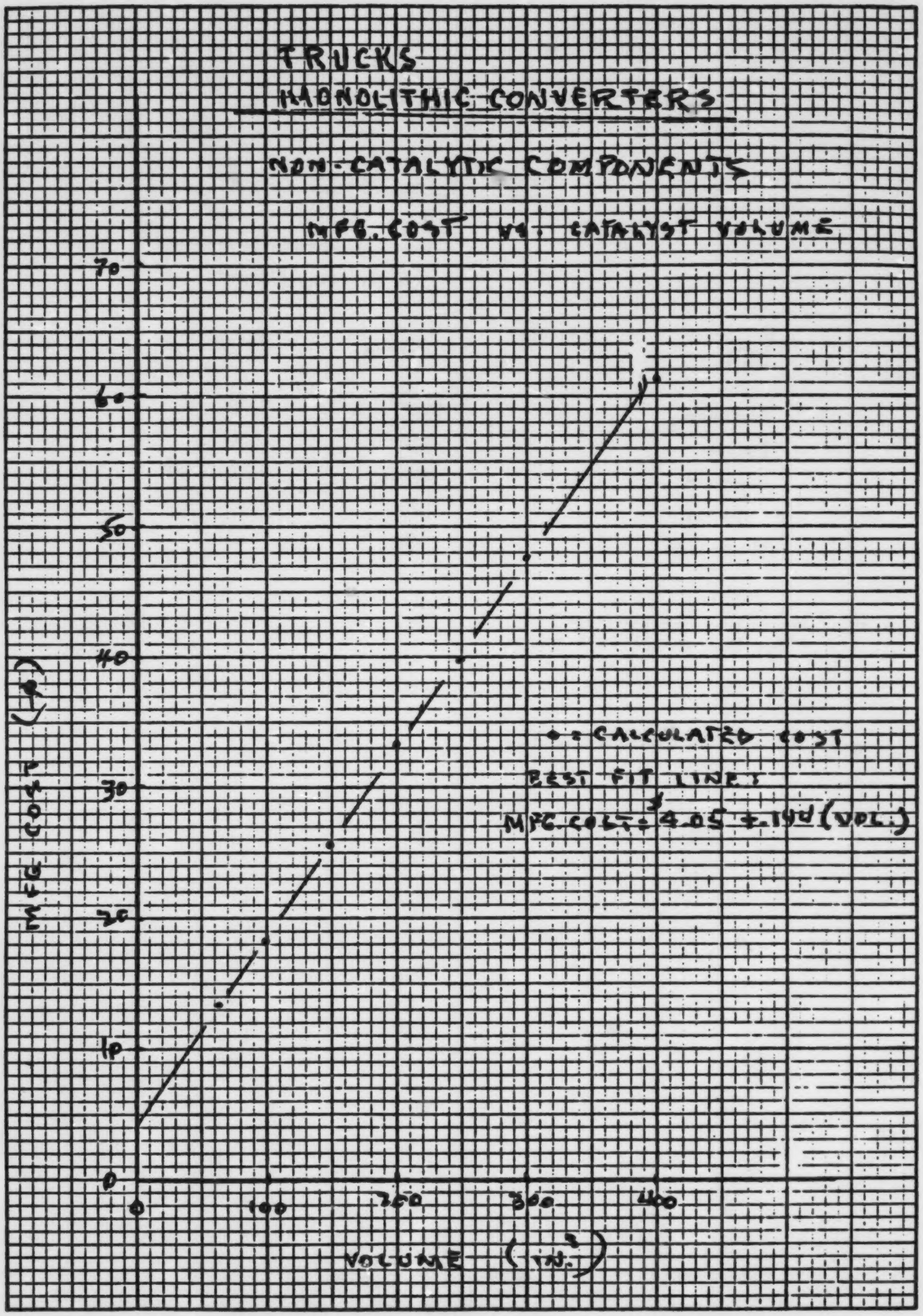

TRUCKS

MONOLITHIC CONVERTERS

NON-CATALYTIC COMPONENTS

MFG. COST VS. CATALYST VOLUME

BEST FIT LINE:
MFG COST = $4.05 + .144 (VOL.)

NO. 31B. 10 DIVISIONS PER INCH BOTH WAYS. 70 BY 100 DIVISIONS. CODEX GRAPH PAPER ® IN STOCK DIRECT FROM CODEX BOOK CO., NORWOOD, MASS. 02062 PRINTED IN U.S.A.

MFG. COST CALCULATIONS - NONCATALYTIC COMPONENTS, MONOLITHIC CONVERTERS

Vol. - 63 (Base) Dia. - 4 Lgth. - 7.2

Part	Mat'l	Weight	[1]Mat'l Cost	[2]Labor	OH	Mfg. Cost
Cvtr. Assy.			-	.68	.27	.95
Shell	409 SS	2.00	1.08	.17	.07	1.32
Rings (no.)	409 SS	1.00	.54	.08	.03	.65
In. Cone	409 SS	1.00	.54	.08	.03	.65
Out. Cone	409 SS	1.00	.54	.08	.03	.65
In. Pipe	409 SS	1.00	.54	.08	.03	.65
Flanges	409 SS	.25	.14	.04	.02	.20
Mesh	409 SS	.15	.08	.04	.02	.14
Hdwr.	Steel	.10	.03	.04	.02	.09
Substrt.	Ceramic	1.30	6.32	.34	.14	6.80
Wash Coat	Al_2O_3	-	.81	.17	.07	1.05
	TOTALS		10.62	1.80	.73	13.15

Vol. - 10 Dia. - 4 Lgth. - 2.1

Weight	Mat'l Cost	Labor	OH	Mfg. Cost
.76	.41	.51	.20	.71
.50	.27	.04	.02	.33
1.00	.54	.08	.03	.65
1.00	.54	.08	.03	.65
1.00	.54	.08	.03	.65
.25	.14	.04	.02	.20
.04	.03	.02	.01	.06
.10	.03	.04	.02	.09
.21	1.03	.17	.07	1.27
	.14	.08	.03	.25
	3.67	1.25	.50	5.42

Vol. - 100 Dia. - 4 Lgth. - 10.6

Cvtr. Assy.		9.46	-	.77	.31	1.08
Shell	409 SS	2.83	1.53	.21	.08	1.82
Rings (no.)	409 SS	1.00	.54	.08	.03	.65
In. Cone	409 SS	1.00	.54	.08	.03	.65
Out. Cone	409 SS	1.00	.54	.08	.03	.65
In. Pipe	409 SS	1.00	.54	.08	.03	.65
Flanges	409 SS	.25	.14	.04	.02	.20
Mesh	409 SS	.22	.12	.05	.02	.19
Hdwr.	Steel	.10	.03	.04	.02	.09
Substrt.	Ceramic	2.06	10.03	.46	.18	10.67
Wash Coat	$Al_2 O_3$		1.28	.23	.09	1.60
	TOTALS		15.29	2.12	.84	18.25

Vol. - 150 Dia. - 4 Lgth. - 15.4

12.27	-	.93	.37	1.30
4.00	2.16	.27	.11	.54
1.50	.81	.13	.05	.99
1.00	.54	.08	.03	.65
1.00	.54	.08	.03	.65
1.00	.54	.08	.03	.65
.25	.14	.04	.02	.20
.32	.18	.07	.03	.28
.10	.03	.04	.02	.09
3.10	15.08	.62	.25	15.95
	1.95	.31	.12	2.38
	21.97	2.65	1.06	25.68

MFG. COST CALCULATIONS - NONCATALYTIC COMPONENTS

Vol. - 200 Dia. - 5.4 Lgth. - 12.5

Part	Mat'l	Weight	Mat'l Cost	Labor	OH	Mfg. Cost
Cvtr. Assy.		15.60	-	1.11	.44	1.55
Shell	409 SS	4.56	2.46	.30	.12	2.88
Rings (no.)	409 SS	2.03	1.09	.15	.06	1.36
In. Cone	409 SS	1.35	.73	.10	.04	.87
Out. Cone	409 SS	1.35	.73	.10	.04	.87
In. Pipe	409 SS	1.35	.73	.10	.04	.87
Flanges	409 SS	.34	.19	.05	.02	.26
Mesh	409 SS	.35	.19	.08	.03	.30
Hdwr.	Steel	.14	.04	.05	.02	.11
Substrt.	Ceramic	4.13	20.09	.78	.31	21.18
Wash Coat	$Al_2 O_3$		2.57	.39	.16	3.12
	TOTALS		28.82	3.21	1.28	33.31

Vol. - 300 Dia. - 5.4 Lgth. - 18.3

Cvtr. Assy.		20.40	-	1.39	.56	1.95
Shell	409 SS	6.47	3.50	.40	.16	4.06
Rings (no.)	409 SS	2.70	1.46	.20	.08	1.74
In. Cone	409 SS	1.35	.73	.10	.04	.87
Out. Cone	409 SS	1.35	.73	.10	.04	.87
In. Pipe	409 SS	1.35	.73	.10	.04	.87
Flanges	409 SS	.34	.19	.05	.02	.26
Mesh	409 SS	.51	.27	.10	.04	.41
Hdwr.	Steel	.14	.04	.05	.02	.11
Substrt.	Ceramic	6.19	30.11	1.10	.44	31.65
Wash Coat	$Al_2 O_3$		3.86	.55	.22	4.63
	TOTALS		41.62	4.14	1.66	47.42

Vol. - 250 Dia. - 5.4 Lgth. - 15.4

Weight	Mat'l Cost	Labor	OH	Mfg. Cost
17.67	-	1.22	.49	1.71
5.52	2.99	.35	.14	3.48
2.03	1.09	.15	.06	1.30
1.35	.73	.10	.04	.87
1.35	.73	.10	.04	.87
1.35	.73	.10	.04	.87
.34	.19	.05	.02	.26
.43	.23	.09	.04	.36
.14	.04	.05	.02	.11
5.16	24.84	.94	.38	26.16
	3.22	.47	.19	3.88
	34.79	3.62	1.46	39.87

Vol. - 400 Dia. - 5.4 Lgth. - 23.9

25.14	-	1.67	.67	2.34
8.31	4.49	.49	.20	5.18
3.38	1.82	.26	.10	2.18
1.35	.73	.10	.04	.87
1.35	.73	.10	.04	.87
1.35	.73	.10	.04	.87
.34	.19	.05	.02	.26
.67	.36	.13	.05	.54
.14	.04	.05	.02	.11
8.25	40.14	1.42	.57	42.13
	5.14	.71	.28	6.13
	54.37	5.08	2.03	61.48

Equation: Mfg. Cost = \$4.05 + \$.144 (Vol.)

DETERMINATION OF SUBSTRATE AND SHELL DIMENSIONS FOR MONOLITHIC CONVERTERS

Imposed Space Limits to Shell

Diameter Shell - 6.0"
Length Shell - 24.0"

Implied space limits to substrate contained in shell.

Diameter - 6.0 - 0.5 (metal mesh) = 5.5"
Length - 24.0 - 1.1 (endcap) = 22.9"

Two shell diameters were selected to accomodate the range of substrate volumes: (refer to graph)

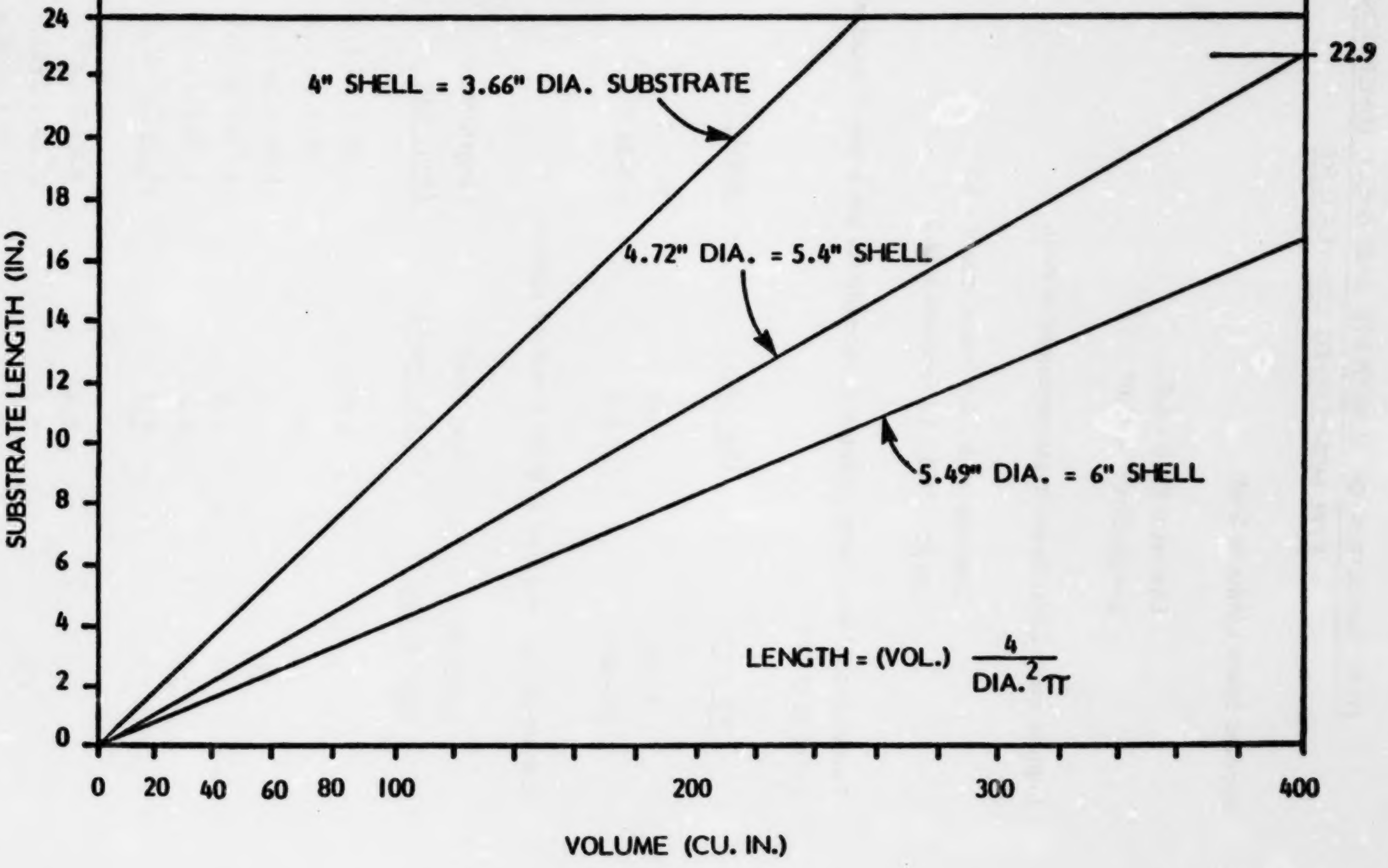
Vol (in)	Dia (in)	Length (in)
0-150	4.0	0-15.1
151-400	5.4	9.7-24.0

Length of shell required at given substrate volume.

Substrate Volume (in)	Dia. Shell (incl. mesh)	Length Shell (incl. cap)
1	4.0	.10+1.1= 1.2
10	4.0	.95+1.1= 2.1
20	4.0	1.90+1.1= 3.0
50	4.0	4.75+1.1= 5.9
100	4.0	9.50+1.1=10.6
150	4.0	14.26+1.1=15.4
151	5.4	8.63+1.1= 9.7
200	5.4	11.43+1.1=12.5
250	5.4	14.29+1.1=15.4
300	5.4	17.15+1.1=18.3
350	5.4	20.00+1.1=21.1

LENGTH OF SUBSTRATE REQUIRED TO ATTAIN VOLUME AT THREE SPECIFIC DIAMETERS

LIMITS: LENGTH 24" MAX. OVERALL SHELL; LESS 1.1 = 22.9" MAX. LENGTH OF SUBSTRATE
VOLUME 400 IN^3 MAX.



$$\text{LENGTH} = (\text{VOL.}) \frac{4}{\text{DIA.}^2 \pi}$$

DETERMINATION OF RING DIAMETER

Volume Substrate In.	Dia. Ring In.
0-150	4.0
151-400	5.4

ID - AIR-FUEL METERING SYSTEMS
HEAVY DUTY GASOLINE ENGINES

The detailed descriptions and calculations following this page apply to passenger car parts, reprinted from a previous report EPA - 78 - 002, March, 1978. The costs shown therein have been adjusted by using factors, described later in this report, that reflect differences in size and in manufacturing volume (economy of scale) between automobiles and trucks. The EOS user for automobiles is 350,000 per year; for trucks, 50,000.

The resulting retail price equivalent costs for trucks are shown below.

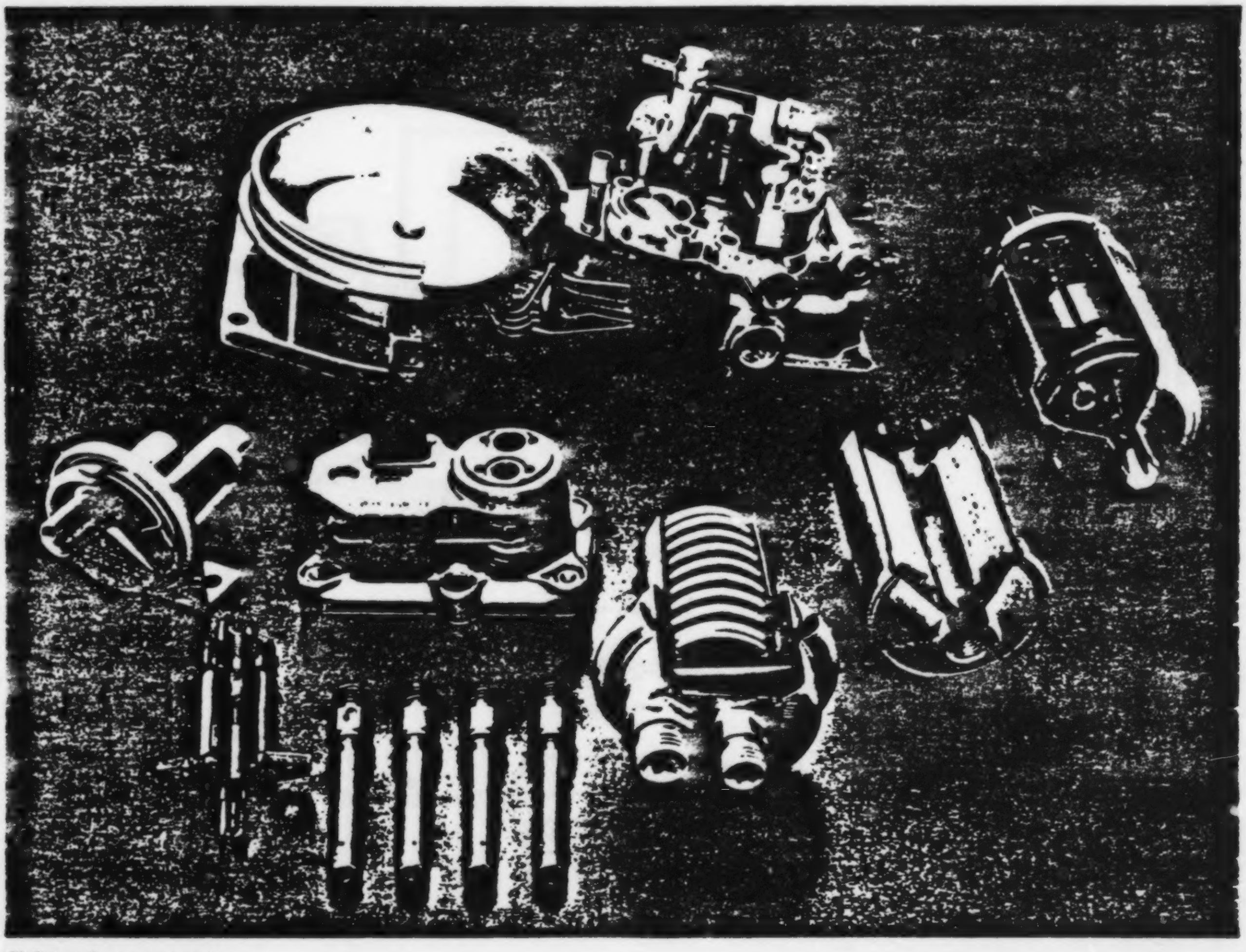
1. Electronic Fuel Injection

Interpolation for an EOS of 50,000 from Table 1, using the .914 decrement factor:

Truck OEM Cost = $162.62

Adding Mark-ups (x2.2)

Truck Retail Price Equivalent	$357.76



K-Jetronic components

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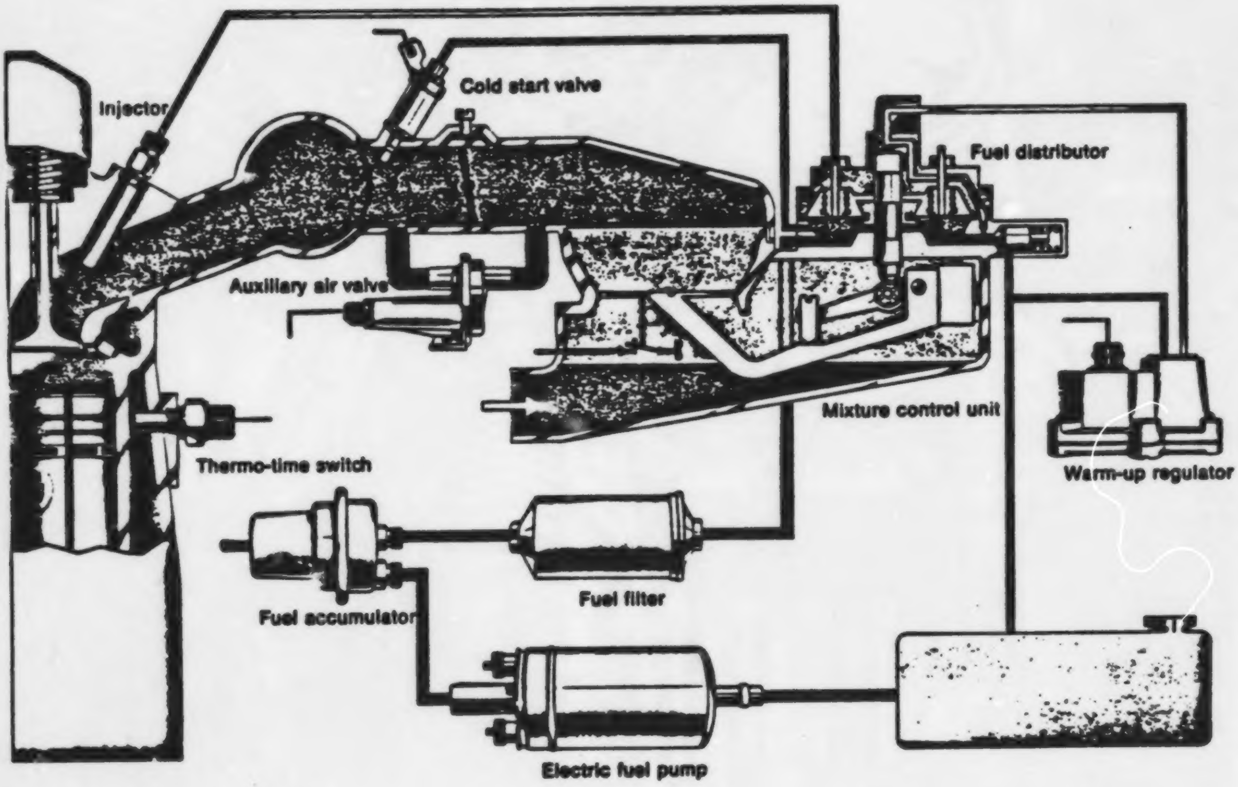
The cone in which the sensor plate rises can be shaped for individual specifications of air-fuel ratios for various load levels. Plate position is transmitted directly by lever to the fuel-distributor control plunger.

Plunger movement is countered by a hydraulic fuel force which can be modulated by the warm-up regulator for mixture enriching. Full-load enrichment is also possible.

K-Jetronic from Bosch:
Continuous Injection System (CIS)


Injector
Cold start valve
Fuel distributor
Auxiliary air valve
Mixture control unit
Thermo-time switch
Warm-up regulator
Fuel filter
Fuel accumulator
Electric fuel pump

Schematic of K-Jetronic

In the K-Jetronic, the air-flow through the induction system is measured directly without electronics or mechanical drive.

In the mixture control unit, the air-flow sensor plate is deflected against the hydraulic force of regulated fuel pressure. The fuel is continuously metered by control slits and downstream differential-pressure valves.

At each cylinder, fuel is injected continuously at the proper rate through an injector at the intake port.

Electronic Fuel Metering System

(Bosch, Bendix, and Chrysler System)

The EFI-L (Electronically-Controlled Fuel Injection System, Air-Flow Sensitive), is an intermittently operating system, with, low-pressure injection of fuel into the intake manifold. In this system, the quantity of air drawn in by the engine is measured directly, and is used as the main control parameter for the quantity of fuel required. The fuel is metered by solenoid-operated injection valves. These valves are under constant fuel pressure, and, their optimum opening period, which is proportional to the amount of fuel injected, is determined for every operating function of the engine by the electronic control unit on the basis of information received from various electrical sensors.

The electronic fuel injection systems for gasoline piston engines are primarily a development of European technology, although the Bendix Corporation in the U.S.A. has a cross licensing arrangement with Bosch in Germany for technology exchange. No mass production manufacturing facility exists in the U.S.A. to produce electronic fuel injection and electronic emission control subsystems for gasoline piston engines.

Fuel Pumps (39 PSIG)--an electrically-driven motor coupled to a constant-flow rotary pump.

Fuel Filter--a close tolerance filter that eliminates particles that would clog the fuel nozzles.

Fuel intake manifold with provision for mounting the fuel rail.

Fuel nozzles--a precision solenoid operated by the electronic control unit.

Throttle body--the basic air control unit that includes a throttle sensor and a cold-start air control.

Speed sensor unit--the magnet assembly equipped with a reed switch assembly for sensing the engine R.P.M.

Electronic control unit and subsystem--this system provides the control signals and the feedback response from water and air sensors pressure sensors, and a fuel pressure regulator. When combined with most three-way catalyst systems, the ECU includes the capability of receiving feedback from an oxygen sensor and adjusts the air-fuel ratio accordingly.

Oxygen-sensor--the platinum-coated ceramic sensor located in the exhaust stream. This is normally included only with three-way catalyst systems.

The EFI system coupled with a 3-way catalyst system is currently being installed in some European vehicles sold in the U.S.A. most of which are sold in the State of California.

Currently, these units are manufactured and bought in relatively small annual quantities; and, consequently, unit costs are higher than they would be if quantities were increased by several magnitudes. In order to arrive at a logical and consistent method, for realistically estimating future costs at higher purchase quantities, a learning curve methodology has been employed.

Estimates of prices on 5,000; 200,000; and 500,000 lot sizes were solicited from U.S.A. and European sources. (These are shown in the first three columns of Table 1.) Analysis of these figures indicates a learning curve of 91.4%, with individual items deviating, but not significantly, in the overall. (A 91.4% curve means an 8.6% decrease in unit cost for each doubling of the quantity.)

The last two columns in Table 1 are mathematical extrapolations of the 500,000 price by .914 and .742 respectively to estimate prices for 1,000,000 and 5,000,000 units.

The plan for production of electronic fuel injection systems at various volumes was proposed as:

Year	Volume	Production Plan
1975	5,000	Purchase all the components from known U.S.A. and European sources.
1976/77	200,000	Start manufacturing nozzles, throttle devices, fuel pumps, and ECU units. Purchase mass production loading.
1978/79	500,000	Redesign the ECU using integrated circuits and combine some of the e external serve functions into the ECU. Provide for mass production facilities of the major components. Include the major valves as manufactured items.
1979/80	1,000,000/ 5,000,000	Develop a new cost reduction design and include the balance of the items in the manufacturing program. Tool up the final mass production facilities for all components.

The total investment for such a facility to produce 5,000,000 units per year would be $55,000,000, which includes launching costs and equipment costs. Over $11,300,000 would be expended for tooling the nozzles.

Table 1 - OEM COSTS--8-CYLINDER SYSTEM

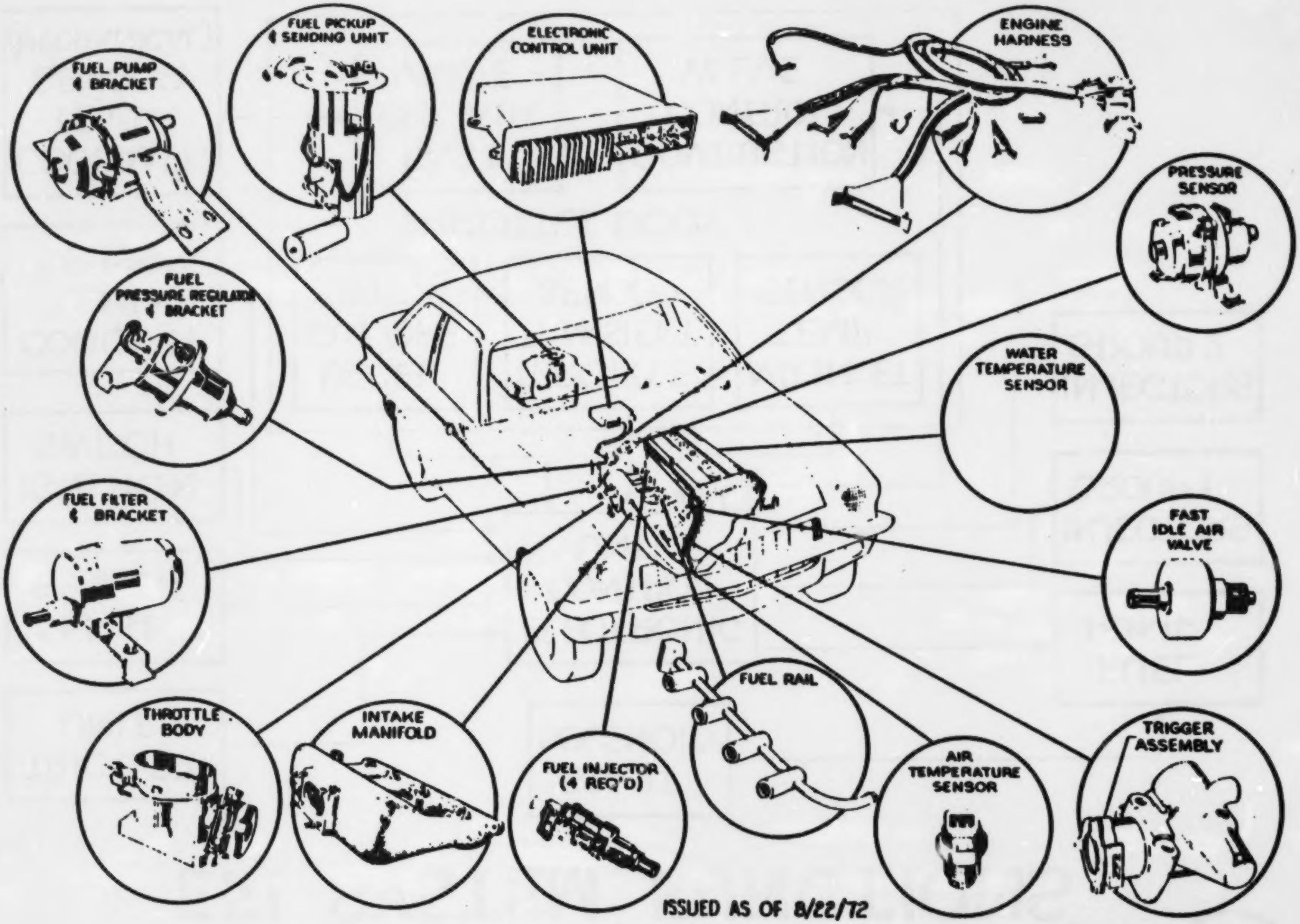
	Industry Estimates			Projected Estimates	
Quantity	5 K	200 K	500 K	1,000 K	5,000 K
Injectors	$ 56.00	$ 40.00	$ 32.00	$ 29.25	$ 23.74
O_2 Sensor *	6.00	4.50	2.36	2.16	1.75
ECU	75.00	45.00	45.00	41.13	33.39
Air Temperature	1.75	1.75	1.25	1.14	.93
H_2O Temperature	1.75	1.75	1.25	1.14	.93
Throttle Switch	3.00	3.00	2.30	2.10	1.71
Fuel Pump Assembly	15.00	15.00	12.00	10.97	8.90
Fuel Pressure Regulator	3.00	2.90	2.57	2.35	1.91
Fast Idle Valve	5.00	3.51	2.00	1.83	1.48
Throttle Body	10.00	8.78	5.00	4.57	3.71
Air Solenoid Valve	4.00	3.25	2.00	1.83	1.50
Fuel Filter	3.50	2.00	1.00	.91	.74
Fuel Rail	8.50	6.00	5.00	4.57	3.71
Speed Sensor	1.50	1.00	.75	.69	.56
Intake Manifold					
Wiring Harness	25.20	10.00	5.00	4.57	3.71
	$219.20	$148.44	$119.48	$109.21	$ 88.67

*Normally used with three-way catalyst systems only.

The sticker price contribution for feedback controlled EFI systems installed in various size vehicles and engines at a production volume of 5,000,000 units would be:

Vehicle	Cyl. CID	Mfg. Cost	Markup	Sticker Price
Subcompact	4 - 140	$76.80	1.8	$138.00
Compact	6 - 250	82.97	2.0	166.00
Standard	8 - 350	88.67	2.2	195.00

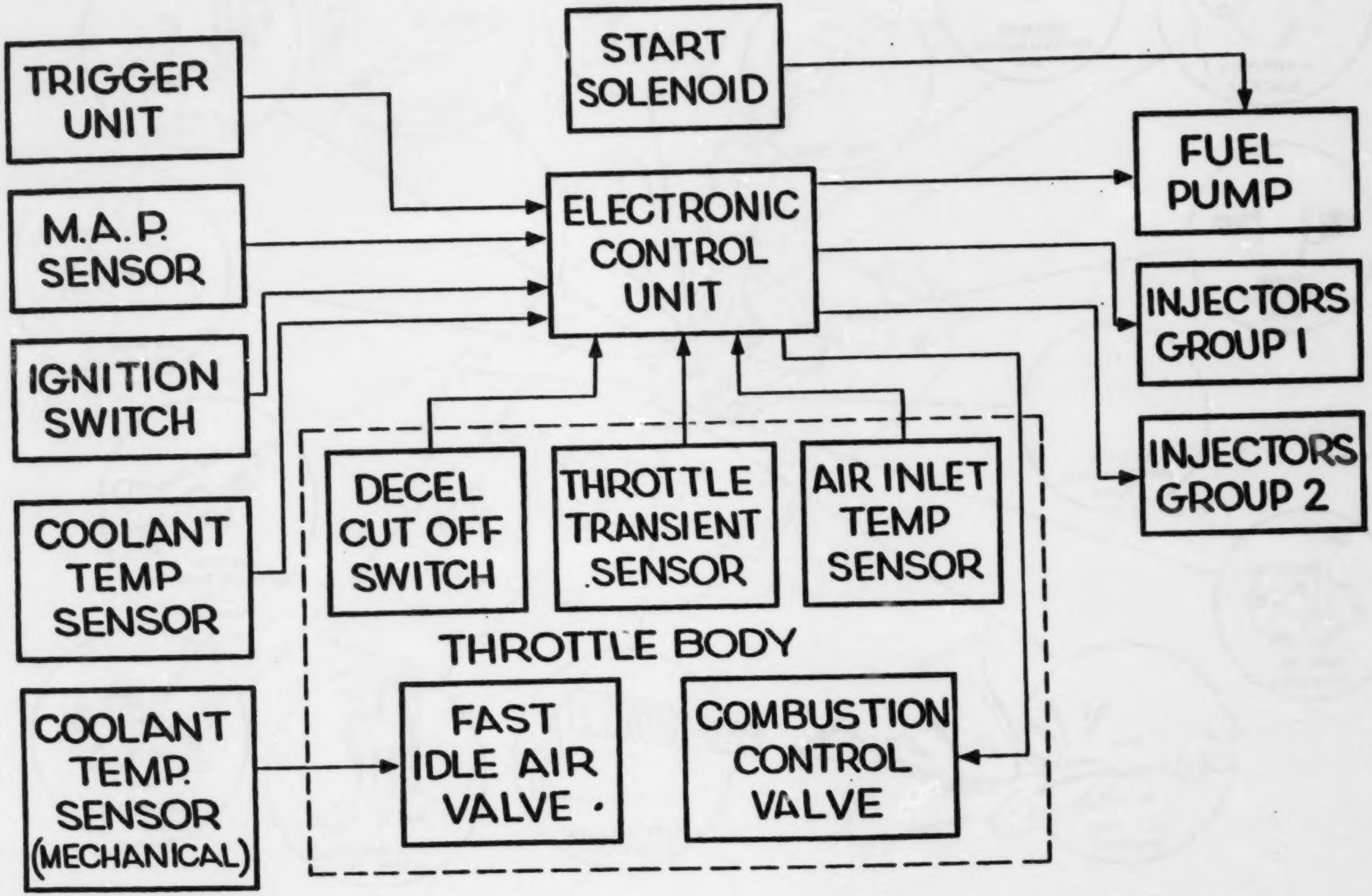
When making comparisons to feedback controlled carbureted systems for these same engines, the control valves, sensors, and feedback controls must be included. Also, a more sophisticated carburetor, valued at $18 to $24 manufacturing costs, has to be considered. The author has created the delta costs to achieve several levels of emissions. When making comparisons of feedback controlled EFI and carbureted systems, to achieve the same levels of emissions, the cost deltas are not significantly different at the vehicle sticker price level.


FUEL PUMP & BRACKET
FUEL PICKUP & SENDING UNIT
ELECTRONIC CONTROL UNIT
ENGINE HARNESS
PRESSURE SENSOR
FUEL PRESSURE REGULATOR & BRACKET
WATER TEMPERATURE SENSOR
FUEL FILTER & BRACKET
FAST IDLE AIR VALVE
THROTTLE BODY
INTAKE MANIFOLD
FUEL INJECTOR (4 REQ'D)
FUEL RAIL
AIR TEMPERATURE SENSOR
TRIGGER ASSEMBLY

ISSUED AS OF 8/22/72

Bendix Electronic Fuel Injection Division

EFI SYSTEM FUNCTIONS


TRIGGER UNIT
M.A.P. SENSOR
IGNITION SWITCH
COOLANT TEMP SENSOR
COOLANT TEMP. SENSOR (MECHANICAL)
START SOLENOID
ELECTRONIC CONTROL UNIT
FUEL PUMP
INJECTORS GROUP 1
INJECTORS GROUP 2
DECEL CUT OFF SWITCH
THROTTLE TRANSIENT SENSOR
AIR INLET TEMP SENSOR
THROTTLE BODY
FAST IDLE AIR VALVE
COMBUSTION CONTROL VALVE

Electronic Control Unit

The Electronic Control Unit is the heart of the EFI system. Its function is to deliver fuel to the engine at a rate which is a function of continuously measured engine input and output parameters. The current production model ECU also provides fuel pump power control, engine start auziliary air control, and exhaust gas recirculation (EGR) on/off control.

The circuit design architecture of the Electronic Control Unit, relies on several production technologies. Four custom bipolar integrated circuits implement the core control law function that is common to all ECU calibrations. These circuits are contained on a ceramic thick-film substrate module. Unique circuit functions are implemented using standard bipolar integrated circuits and discrete components. Thick-film laser trimmed passive resistor networks are incorporated to realize base calibration, and each individual production unit is final trimmed to meet performance specifications. Additional components include the intake manifold pressure sensor, two power relays, and a custom hard mounted connector. All components are mounted on two printed circuit boards, which are conformal coated for environmental protection.

The Electronic Control Unit is installed in the passenger compartment behind the dash panel. It is designed to function at a maximum temperature of 185°F (85°C). In the current production model, no attempt was made to maximize compactness; rather, functional and calibration flexibility were deliberately designed into the unit to accommodate anticipated changes and improvements which were indeed made during the development stage.

Sensors

Intake manifold absolute pressure is measured with an accuracy of ± 1 percent, using an aneroid, linear variable differential transformer sensor device. This sensor is mounted on the ECU printed circuit board to implement concurrent calibration of sensor and ECU and to increase reliability by minimizing the number of electrical connections between the sensor and the computing circuits.

Engine speed is sensed using two magnetic reed switches mounted on the ignition distributor casting, adjacent to the drive shaft. Installed on the drive shaft is a magnet assembly. This sensor provides engine phasing as well as engine speed data.

Engine water temperature and intake manifold air temperature are sensed using a high temperature coefficient precision resistor, formed from nickel wire wound on a bobbin, which is epoxy encased. The sensor output is precise and linear over the temperature range encountered.

Data on throttle position and rate of change of throttle motion are provided by a rotating shaft sensor. Mechanical contacts on the shaft slide over a printed circuit board on which electric current carrying tracks are mounted. Rotational information is realized when tracks are crossed as the throttle moves. The discrete voltage levels sensed are processed in the ECU to yield the required data.

Injectors

The fuel valving, metering, and atomizing functions are performed by the injectors, which are located, one for each cylinder, in the vicinity of the intake valves. These injectors are essentially solenoid actuated on/off poppet valves incorporating pintles designed for metering and atomization. Since a constant fuel pressure differential is maintained across the injector, the rate of fuel delivery is proportional to the injector open time, which varies from 2.5 to 10 milliseconds.

Air Flow Calculating Versus Air Flow Sensing EFI Systems

The first generation of Bosch EFI systems were called the D-Jetronic, where D stands for Druck, which means pressure in German. This name is derived from the fact that one of the main inputs to this sytem is intake manifold pressure. In this system the fuel loop consists of the fuel pump, the fuel filter, and the fuel pressure regulator. With constant fuel pressure applied to the injectors, the amount of fuel injected on a per stroke basis is proportional to the timing of the regulator which can be controlled. Air flow can be calculated using displacement, engine speed and manifold density, and the desired air/fuel ratio can be obtained by changing the injector on time.

The next generation of Bosch EFI system was the L-Jetronic system, where L stands for Luftmengenmessung, which means air flow measurement in German. In this system the fuel loop is basically the same as in the D-Jetronic system except that the fuel pressure regulator is connected by a hose to the intake manifold so that the fuel pressure is a function of the manifold pressure and the pressure loop across the injectors is thus kept constant.

Also, in this system, the air flow rate is measured by an air flow meter whose moveable measuring plate is opened by the air stream against the force of a spring. The position of the measuring plate is sensed by a potentiometer. Its voltage is proportional to the volume of air flow and is one of the main input signals into the electronic control unit. The second input is engine speed taken from the distributor.

Measurement of air flow is said by Bosch to exhibit the following advantages.

1. Compensation of tolerances which are due to wear, deposits in the combustion chamber, or changes in the valve adjustments.
2. Compensation of engine speed-dependent volumetric efficiency.
3. No necessity of acceleration enrichment because the air flow signal precedes the filling of the cylinders.
4. Improved idling stability.
5. Insensitivity to changes in the exhaust back pressure caused by thermal or catalytic reactors.
6. Insensitivity of the system to EGR because only the fresh air portion is measured.

Closed Loop/Electronic Fuel Injection Systems

The term closed loop requires some discussion. One use of the term closed loop is to describe adaptive systems where feedback of output directly influences the input. This is so called extremum seeking adaptive control. Another use of the term closed loop is to describe systems where the output is used for error correction to some programmed parameter. Current closed loop fuel management systems are of this latter type.

HEAVY DUTY GASOLINE ENGINES

3. Standard Carburetor

The detailed descriptions and calculations following this page apply to passenger car parts, reprinted from a previous report EPA - 78 - 002, March, 1978. The costs shown therein have been adjusted by using factors, described later in this report, that reflect differences in size and in manufacturing volume (economy of scale) between automobiles and trucks. The EOS used for automobiles is 350,000 per year; for trucks, 50,000.

The resulting retail price equivalent costs for trucks are shown below.

	Automobile Unit Cost	EOS Factor
Material	3.78	1.3
Labor and Overhead	8.75	2.7
Equipment	1.58	2.4
Tooling	.40	3.4
Weighted EOS Factor		2.3

		Carb-1	Carb-2	Carb-3
x	Automobile RPE	$22.60	$26.62	$35.15
=	Truck RPE	$51.98	$61.23	$80.85

Standard Carburetor

The standard carburetor is a complex system of components that provides appropriate mixtures of air and fuel to the intake manifold throughout the various driving cycles of the vehicle.

One of these carburetors is the Holley Model 1945. This carburetor is a single venturi concentric downdraft carburetor equipped on 225 CID 6-cylinder engines. It consists of the following subsystems:

1. Fuel inlet system
2. Idle system
3. Main Metering system
4. Power enrichment system
5. Accelerating pump system
6. Automatic Choke Vacuum Kick system

The dual barrel carburetors such as Carters BBD and the Holley 2245 include an added subsystem called the idle enrichment system. This carburetor is used on 318-V8 CID engines.

The Carter TQ carburetor is a 4-barrel carburetor designed for 360, 400, and 440 CID V8 engines. The subsystems include both low and high speed performance circuits. This carburetor is also designed to incorporate an altitude compensation system. This system will be treated separately in another section of this report.

The basic data for 1975 vehicles are:

Carburetor Part No.	List Price $	Weight lbs.	Vehicle
3830576	$112.00	5.550	Valiant 225
3830565	79.35	4.510	Satellite 318
3830563	87.24	6.710	Fury 360

Choke Part No.	List Price $	Weight lbs.	Vehicle
3830549	$ 10.22	.250	Valiant
3830512	7.25	.190	Satellite
3751476	12.55	.250	Fury (et al)

Source: Chrysler Data

The costs will be gross estimates since a complete analysis involves estimating between 100 to 230 components.

These carburetors provide an interface subsystem for EGR systems.

Standard Carburetor
Manufacturing Costs
Bill of Material

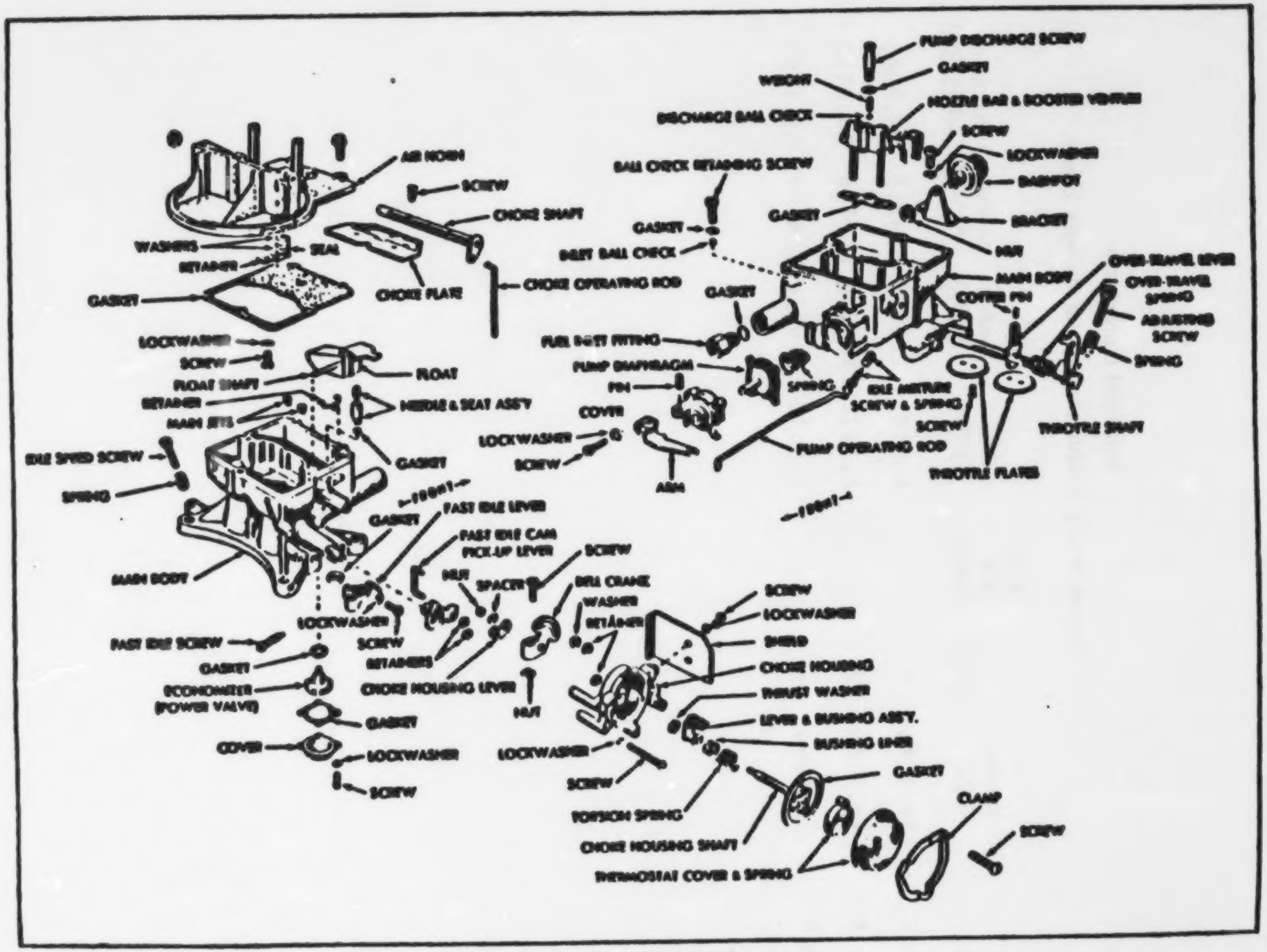
	Material	Weight	Material Costs	Labor Costs	Labor Overhead	Manufacturing Costs	Reference
Carburetor 1		4.510					
Primary Parts	Alum.	4.014	2.4084	3.5000	1.4000	7.3084	
Secondary Parts		.496	.0992	.4000	.1600	.6592	
Total			2.5076	3.9000	1.5600	7.9676	
Carburetor 2		5.500					
Primary Parts	Alum.	4.895	2.9370	4.2000	1.6800	8.8170	
Secondary Parts		.605	.1210	.5000	.2000	.8210	
Total			3.0580	4.7000	1.8800	9.6380	
Carburetor 4		6.710					
Primary Parts	Alum.	5.472	3.2822	5.2500	2.1000	10.6322	
Intermediate Pts	Phenolic	.500	.3500	.3000	.1200	.7700	
Secondary Parts	Steel	.738	.1476	.7000	.2800	1.1276	
Total			3.7798	6.2500	2.5000	12.5298	
Choices	Steel	.250	.050	.3500	.1400	.5400	

Standard Carburetor
Tooling Costs
Amortization Per Piece

Part	Economic Volume	1 Year Recurring Tooling	3 Year Nonrecurring Tooling	12 Year Machinery and Equipment	12 Year Launching Costs	40 Year Land and Building	Amortization per Piece
		.1000	.2000	1.0000	.1000		
Carburetor 1	1,000,000	100,000	600,000	12,000,000	1,200,000		1.4000
		.1000	.1333	1.0000	.0625		
Carburetor 2	2,000,000	200,000	800,000	24,000,000	1,500,000		1.2955
		.1500	.2500	1.5000	.0833		
Carburetor 4	2,000,000	300,000	1,500,000	36,000,000	2,000,000		1.9833

Standard Carburetor
Total Manufacturing Costs

	Material Costs	Labor Costs	Plant Overhead	Plant Mfg. Costs	Tooling		Corp. Alloc. .20 MC	Corp. Profit .20MC	Mfg. Vendor Costs
					Exp.	Inv.			
Carburetor 1	2.5076	3.9000	1.5600	7.9676	.3000	1.100	1.5935	1.5935	12.5546
Carburetor 2	3.0580	4.7000	1.8800	9.6380	.2333	1.0625	1.9276	1.9276	14.7890
Carburetor 4	3.7798	6.2500	2.5000	12.5298	.4000	1.5833	2.5060	2.5060	19.5250


AIR HORN
SCREW
CHOKE SHAFT
WASHING
SEAL
RETAINER
GASKET
CHOKE PLATE
CHOKE OPERATING ROD
LOCKWASHER
SCREW
FLOAT SHAFT
FLOAT
RETAINER
NEEDLE & SEAT ASS'Y
MAIN JETS
IDLE SPEED SCREW
GASKET
SPRING
GASKET
FAST IDLE LEVER
FAST IDLE CAM PICK-UP LEVER
MAIN BODY
NUT
SPACER
SCREW
BELL CRANK
WASHER
RETAINER
LOCKWASHER
SCREW
FAST IDLE SCREW
RETAINERS
GASKET
CHOKE HOUSING LEVER
ECONOMIZER (POWER VALVE)
NUT
GASKET
COVER
LOCKWASHER
SCREW
PUMP DISCHARGE SCREW
GASKET
WEIGHT
NOZZLE BAR & BOOSTER VENTURI
DISCHARGE BALL CHECK
SCREW
LOCKWASHER
BALL CHECK RETAINING SCREW
DASHPOT
GASKET
BRACKET
GASKET
INLET BALL CHECK
NUT
OVER-TRAVEL LEVER
MAIN BODY
OVER-TRAVEL SPRING
GASKET
COTTER PIN
ADJUSTING SCREW
FUEL INLET FITTING
SPRING
PUMP DIAPHRAGM
SPRING
IDLE MIXTURE SCREW & SPRING
PIN
COVER
SCREW
THROTTLE SHAFT
LOCKWASHER
SCREW
PUMP OPERATING ROD
ARM
THROTTLE PLATES
SCREW
LOCKWASHER
SHIELD
CHOKE HOUSING
THRUST WASHER
LEVER & BUSHING ASS'Y.
LOCKWASHER
BUSHING LINER
SCREW
GASKET
TORSION SPRING
CLAMP
SCREW
CHOKE HOUSING SHAFT
THERMOSTAT COVER & SPRING

Ford two-barrel carburetor

Standard Carburetor

Retail Price Equivalent at the Vehicle Level

Part	Vendor Costs	R&D	Tools and Equip.	Alloc. .20VC*	Profit .20VC*	Markup .40VC*	Price Equivalent
Carb 1	12.5546	-	-	2.5109	2.5109	5.0218	22.5983
Carb 2	14.7890	-	-	2.9578	2.9578	5.9156	26.6202
Carb 4	19.5250	-	-	3.9050	3.9050	7.8100	35.1450

Standard Carburetor

Cost Comparison to Aftermarket Selling Prices

Using the aftermarket prices and the discount data we can make the following comparison to the manufacturing cost estimates.

	List Price	½ Discount		Estimates	
		1/4	1/5	Vendor Cost	RPE
Carb 1	79.35	19.84	15.87	12.55	22.60
Carb 2	87.24	21.81	17.65	14.79	26.62
Carb 4	112.00	28.00	22.40	19.52	35.14

Standard Carburetor

Cost Methodology

The weight and selling price data were obtained from Chrysler engineering data and sales catalogs.

The costs are estimates based on judgment. The estimates are not supported by detail costs of each component. Therefore, these estimates are gross estimates using weight data and material type selections.

Standard Carburetor

Applications

As stated previously, the 1, 2, & 4 barrel carburetors are usually associated with 225 CID, 318 CID, 360 CID and over engines. In recent years, domr 4 barrel applications have been replaced by 2 barrel carburetors.

The altitude compensation and electronic feedback subsystems have been treated separately.

HEAVY DUTY GASOLINE ENGINES

3a Carburetor Modification For Altitude

The detailed descriptions and calculations following this page apply to passenger car parts, reprinted from a previous report EPA - 78 - 002, March, 1978. The costs shown therein have been adjusted by using factors, described later in this report, that reflect differences in size and in manufacturing volume (economy of scale) between automobiles and trucks. The EOS used for automobiles is 350,000 per year; for trucks, 50,000.

The resulting retail price equivalent costs for trucks are shown below.

	Automobile Unit Cost	EOS Factor
Material	.272	1.3
Labor and Overhead	1.629	2.7
Equipment	.080	2.4
Tooling	.182	3.4
Weighted EOS Factor		2.6
x Automobile Retail Price Equivalent		$5.58
= Truck Retail Price Equivalent		$14.51

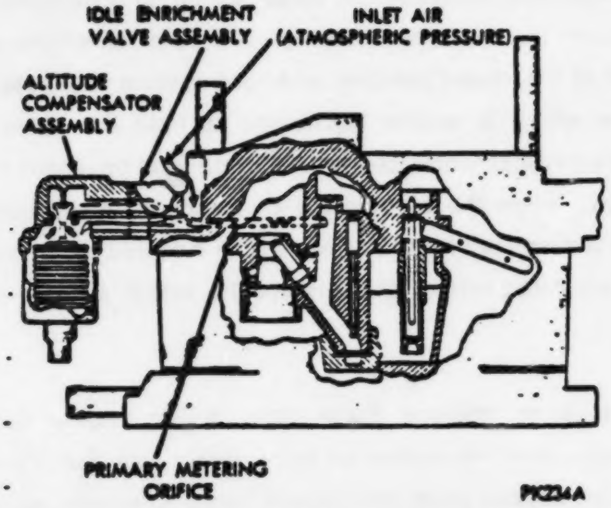
Carburetor Modifications for Altitude Compensation

In order to maintain the appropriate fuel/air mixture while under the influence of a thin atmosphere, a main system altitude compensation circuit has been incorporated into the design of the Thermo-Quad carburetor for most California models. The modification affects the primary metering systems as follows:

A small cylindrical bellows chamber mounted on the front of carburetor, is vented directly to atmosphere. Atmospheric pressure changes expands or contracts the bellows. A small brass tapered-seat valve regulates air flow when it is raised off its seat by the expanding bellows. A small spring is positioned on top of the tapered valve between the valve and housing. The function of the spring is to help maintain the valve in the closed position when the system is exposed to a marginal pressure head (one which is neither sufficient to hold the valve at the proper altitude), and to mechanical vibrations which would tend to unseat the valve during the above condition. When the appropriate environment is encountered and extra air is required, (as determined by the bellows) it is supplied to the primary main air bleeds through a calibrated orifice that meters the proper amount of air to the air bleed.

The system operates as follows: Some time during engine operation a thin atmosphere is encountered, producing an increasingly rich fuel/air mixture. At a mechanically pre-determined point the bellows begin to expand allowing additional air to enter the main air bleeds. The auxiliary air, coupled with the present air source, provides the system with the proper amount of air necessary to maintain the correct fuel/air mixture. The system supplies varying amounts of additional air depending upon different altitudes. When sufficient atmospheric pressure is again restored, the valve closes and the system returns to its normal mode of operation.

CARBURETOR MODIFICATIONS FOR ALTITUDE COMPENSATION


IDLE ENRICHMENT
VALVE ASSEMBLY
INLET AIR
(ATMOSPHERIC PRESSURE)
ALTITUDE
COMPENSATOR
ASSEMBLY
PRIMARY METERING
ORIFICE
PK234A

Altitude Compensator System

Carburetor Modificaitons for Altitude Compensation

Manufacturing Costs Bill of Material

Part	Material	Weight	Material Costs	Labor Costs	Labor Overhead	Manufacturing Costs	Reference
Altitude Comp. Asm.		.400	-	.1250	.0500	.1750	Chrysler
Carburetor Mod		.100	.0600	.2500	.1000	.4100	
Aneroid	Copper	.120	.0960	.2500	.1000	.4460	
Valve	Steel	.050	.0100	.1250	.0500	.1850	
Cup	Steel	.050	.0100	.0625	.0250	.0975	
Valve Hsg.	Alum	.150	.0900	.3500	.1400	.5800	
Hardware		.030	.0060	.0010	.0004	.0074	
Total						1.9009	

Carburetor Modifications for Altitude Compensation
Tooling Costs Amortization Per Piece

Part	Economic Volume	1 Year Recurring Tooling	3 Year Nonrecurring Tooling	12 Year Machinery and Equipment	12 Year Launching Costs	40 Year Land and Building	Amortization Per Piece
Alt. Comp. Asm.	1,000,000	.0100 10,000	.0100 30,000	.0020 24,000	.0002 24,000	-	.0222
Carburetor Mod	1,000,000	.0200 20,000	.0200 60,000	.0200 240,000	.0020 24,000	-	.0620
Aneroid	1,000,000	.0300 30,000	.0300 90,000	.0100 120,000	.0010 12,000	-	.0710
Valve	1,000,000	.0100 10,000	.0100 30,000	.0100 120,000	.0010 12,000	-	.0310
Cup	1,000,000	.0100 10,000	.0100 30,000	.0100 120,000	.0010 12,000	-	.0310
Valve Hsg.	1,000,000	.0300 30,000	.0300 90,000	.0200 240,000	.0020 24,000	-	.0820
Hardware	10,000,000	.0010 10,000	.0010 30,000	.0010 120,000	.0001 12,000	-	.0031
Total							.3023

Research & Development - $250,00 per year for 3 years for 1,000,000 units per year - .25 per carburetor.

Carburetor Modifications for Altitude Compensation

Total Manufacturing Costs

Part	Material	Labor	Plant Overhead	Mfg. Costs	Tooling Exp.	Tooling Inv.	Corp. Alloc. .20MC*	Corp. Profit .20MC*	Vendor Mfg. Costs
Alt. Comp. Asm.	-	.1250	.0500	.1750	.0200	.0022	.0350	.0350	.2672
Carburetor Mod	.0600	.2500	.1000	.4100	.0400	.0220	.0820	.0820	.6360
Aneroid	.0960	.2500	.1000	.4460	.0600	.0110	.0892	.0892	.6954
Valve	.0100	.1250	.0500	.1850	.0200	.0110	.0370	.0370	.2900
Cup	.0100	.0625	.0250	.0975	.0200	.0110	.0195	.0195	.1675
Valve Hsg.	.0900	.3500	.1400	.5800	.0600	.0220	.1160	.1160	.8940
Hardware	.0060	.0010	.0004	.0074	.0020	.0011	.0015	.0015	.0135
Total	.272	1.6289			.182	.0803			2.9636

Carburetor Modification for Altitude Compensation Retail Price Equivalent at the Vehicle Level

Part	Plant Vendor Costs	R&D	Tools and Equip.	Corp. Alloc. .20VC*	Corp. Profit .20VC*	Dealer Markup .40VC*	Vehicle Retail Price Equivalent
Alt. Comp.Asm.	2.9636	.2500	-	.5927	.5927	1.1854	5.5844

Carburetor Modification for Altitude Compenstion Cost Comparison to Aftermarket Selling Prices

The only data obtainable for the delta increase in carburetor aftermarket selling prices is to compare the California 1977 system with the 49 state carburetor system.

The 2 barrel carburetor prices show a delta of about $20 or about $5.00 if the 1/4 discount is used. The manufacturing/vendor estimate is $2.9636 and the RPE is $5.5844. Since we do not know what the delta price includes this comparison is not conclusive.

Carburetor Modification for Altitude Compensation Cost Methodology

Using the Chrysler sketch the unit weight of the components was estimated. The materials are also estimated. The costs are based on an ecomony of scale of 1,000,000 units per year.

Carburetor Modification for Altitude Compensation Applications

It can be assumed that the altitude compensation system will be similar for 1, 2, and 4 barrel carburetors. The costs per system might be slightly less but not significant for this study.

3b Carburetor Modification for Feedback Control

The detailed descriptions and calculations following this page apply to passenger car parts, reprinted from a previous report EPA - 78 - 002, March, 1978. The costs shown therein have been adjusted by using factors, described later in this report, that reflect differences in size and in manufacturing volume (economy of scale) between automobiles and trucks. The EOS used for automobiles is 350,000 per year; for trucks, 50,000.

The resulting retail price equivalent costs for trucks are shown below.

	Automobile Unit Cost	EOS Factor
Material	.87	1.3
Labor and Overhead	2.00	2.7
Equipment	.10	2.4
Tooling	.26	3.4
Weighted EOS Factor		2.4
X Automobile Retail Price Equivalent		$8.17
= Truck Retail Price Equivalent		$19.61

Carburetor Modifications for Feedback Control

The pictorial schematic in Figure 2 shows the system elements of the basic system. The O_2 sensor, located in the exhaust stream between the engine and the catalyst, produces a voltage of about 800 millivolts in the absence of oxygen in the exhaust. This voltage decreases to zero as the oxygen in the exhaust stream increases from 0 to 1½%.

The voltage signal from the sensor is the prime control input to the electronic control unit which provides a square wave output signal of constant frequency, but of variable band width depending on the O_2 sensor voltage. The ECU is designed so that at low values of oxygen in the exhaust (highest level of sensor voltage output), the output signal band width is the greatest. Conversely, as the oxygen concentration increases in the exhaust and the sensor voltage decreases, the band width decreases.

This variable width output signal operates the vacuum control valve, which serves to modulate the vacuum that is applied to the carburetor from the vacuum storage canister. Because the "on time" of the valve is a function of O_2 sensor signal, the modulated vacuum resulting from variable "on time" is also a function of O_2.

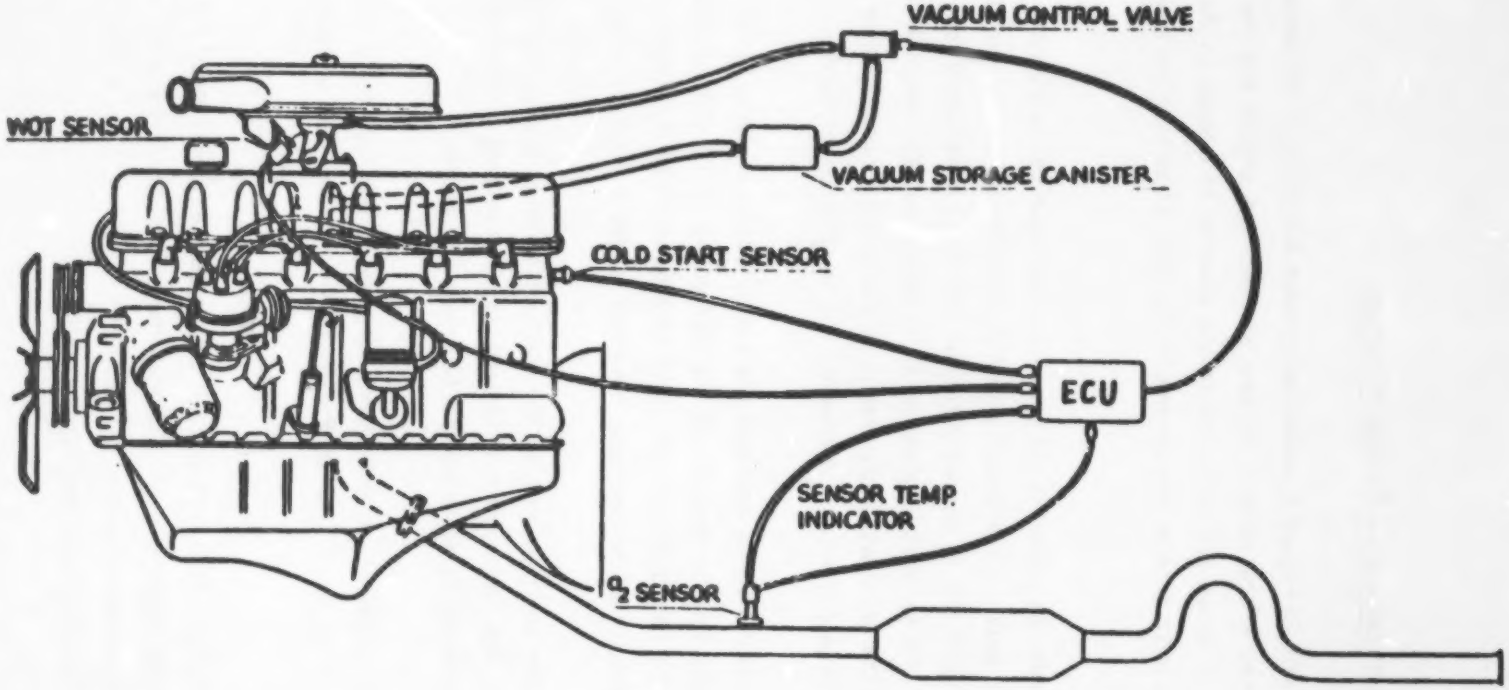
The sensor shows the two systems in the carburetor that are controlled by the modulated vacuum. The idle system is controlled by providing a variable air bleed parallel with the normal air bleed to control idle metering forces.

Control of the main system is accomplished by varying the fuel orifice in parallel with the main metering jet. This construction is a refinement of today's power enrichment system.

In operation, when a high vacuum is applied to the carburetor, it will tend to meter lean. This is accomplished when the solenoid has a high percentage of "on" time. Conversely, when the solenoid is off or operating at a low "on" time level, the control vacuum is low and the carburetor metering will enrichen.

FIGURE 2

HOLLEY FEEDBACK CARBURETOR ENGINE SYSTEM


VACUUM CONTROL VALVE
WOT SENSOR
VACUUM STORAGE CANISTER
COLD START SENSOR
ECU
SENSOR TEMP. INDICATOR
O_2 SENSOR

PATENT PENDING 1976 HOLLEY CARBURETOR DIVISION

Carburetor Modifications for Feedback Control Unit

TOOLING COSTS

Amortization per Piece

Part	Economic Volume Per Year	1-Year Recurring Tooling	3-Year Non Recurring Tooling	12-Year Machinery Equipment	12-Year Launching Costs	40-Year Land & Buildings	Amortization Per Piece
Mod Carb Assy	1,000,000	.0500 50,000	.0500 150,000	.0200 240,000	.0020 24,000	--	.1220
Mod Carb	1,000,000	.0500 50,000	.0500 150,000	.0500 600,000	.0050 60,000	--	.1550
Fix Idle Bleed	1,000,000	.0050 5000	.0050 15,000	.0010 12,000	.0001 1200	--	.0111
Idle FB Valve	1,000,000	.0100 10,000	.0100 30,000	.0100 120,000	.0010 12,000	--	.0310
FB Main Valve	1,000,000	.0100 10,000	.0100 30,000	.0100 120,000	.0010 12,000	--	.0310
Contl Vac Conn	1,000,000	.0050 5000	.0050 15,000	.0010 12,000	.0001 12,000	--	
Total		.1300	.1300	.0920	.0092		.3612

R&D - 300,000/year for 3 years for 1,000,000 units/per = $.30/unit

Carburetor Modifications for Feedback Control Unit

TOTAL MANUFACTURING COSTS

Part	Mat	Labor	Plant Over-Head	Plant Mfg Costs (MC)	Tooling		.20/MC Corp. Costs	.20/MC Corp. Profit	Mfg/ Vend Cost
					Exp.	Inv.			
F.B. Carburetor	.8700	1.4250	.5700	2.8650	.2600	.1012	.5730	.5730	4.3722

Carburetor Modifications for Feedback Control Unit

RETAIL PRICE EQUIVALENT AT THE VEHICLE LEVEL

Part	Vendor Costs (VC)	R&D	Tools and Equip	Corp Allocation .20 VC	Corp Profit .20 VC	Dealer Markup .40 VC	RPE Vehicle Level
FB Carburetor	4.3722	.3000	--	.8744	.8744	1.7489	8.1700

Carburetor Modification for Feedback Control Unit

COST COMPARISON TO AFTERMARKET SELLING PRICES

No aftermarket selling prices are available for a feedback carburetor.

An estimated aftermarket delta might be: 4 x (VC Costs) = 4 x (VC Costs) = 4 x 4.37 = $17.49.

Carburetor Modification for Feedback Control Unit

COST METHODOLOGY

Since we are dealing with a delta change for the carburetor modifications to provide feedback capabilities, all the costs are based on assumptions.

The weight and cost data are estimates based on judgments using the Chrysler sketches.

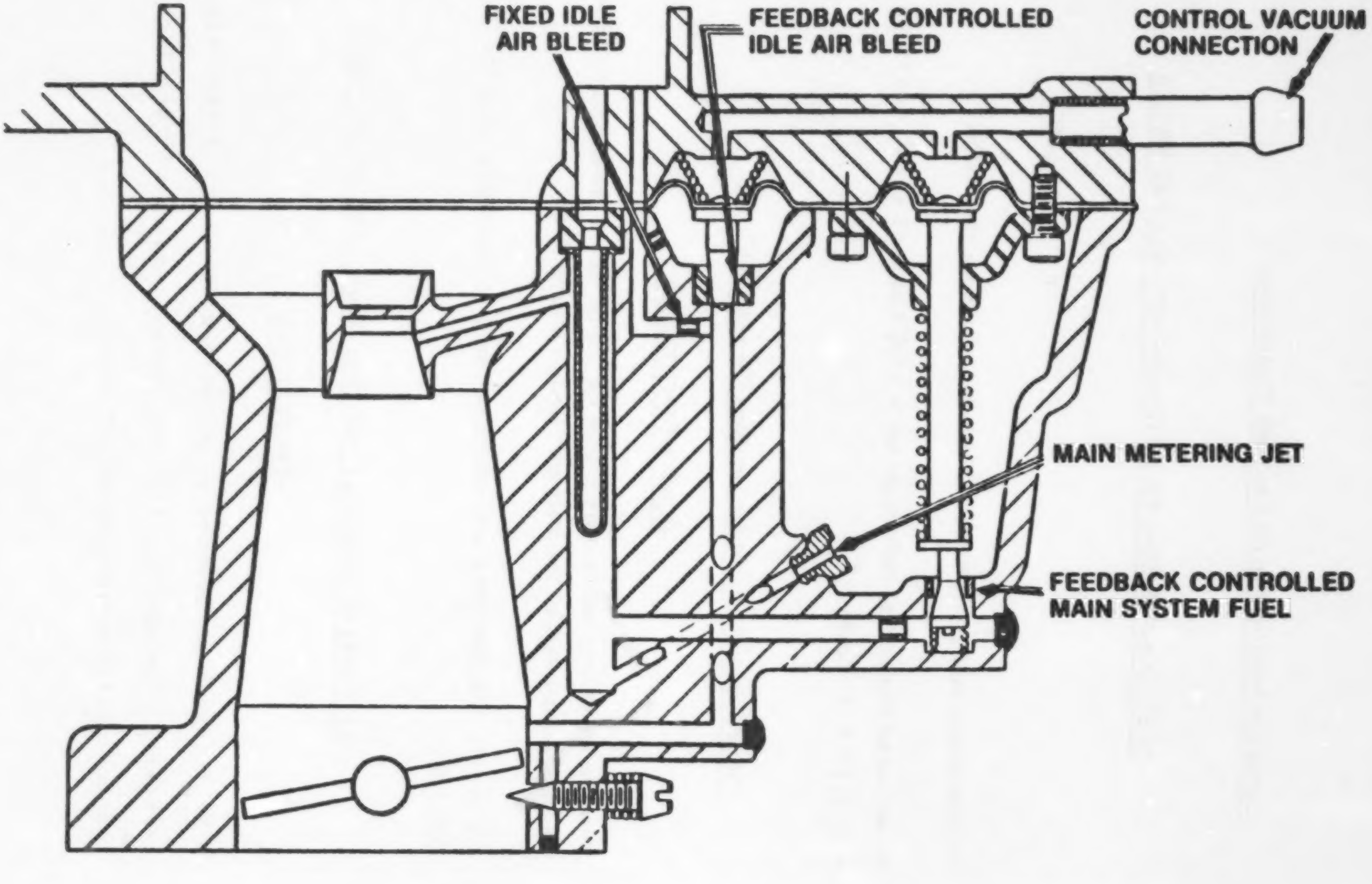
Carburetor Modification for Fecdback Control Unit

APPLICATIONS

The feedback carburetor is associated with the 3-way catalysts systems. The applications to various engines is similar to the design presented by Holley.

FIGURE 3

FEEDBACK CARBURETOR SCHEMATIC DRAWING


FIXED IDLE AIR BLEED
FEEDBACK CONTROLLED IDLE AIR BLEED
CONTROL VACUUM CONNECTION
MAIN METERING JET
FEEDBACK CONTROLLED MAIN SYSTEM FUEL

IE - HEAVY DUTY GASOLINE ENGINES

1. Electronic Control Unit (Microprocessor)

The detailed descriptions and calculations following this page apply to passenger car parts, reprinted from a previous report EPA - 78 - 002, March, 1978. The costs shown therein have been adjusted by using factors, described later in this report, that reflect differences in size and in manufacturing volume (economy of scale) between automobiles and trucks. The EOS used for automobiles is 350,000 per year; for trucks, 50,000.

The resulting retail price equivalent costs for trucks are shown below.

	Automobile Unit Cost	EOS Factor
Material	18.00	1.3
Labor and Overhead	21.70	2.7
Equipment	-	2.4
Tooling	.09	3.4
Weighted EOS Factor		2.1
X Automobile Retail Price Equivalent		$101.21
= Truck Retail Price Equivalent		$212.54

Electronic Control Unit (with sensor inputs for controlling modulated AIR, modulated EGR, modulated A/F, and-modulated spark advance)

Electronic Control Unit

MANUFACTURING COSTS

Bill of Material

Part	Mat Costs Purch.	Labor	Overhead	Mfg. Costs	
ECU Assy		15.50	6.200	21.70	Test
Power Transistor	2.00			2.00	
Rectifier	1.00			1.00	
T^2L 14 Pin DIP	2.00			2.00	
Low Power Trans	.80			.80	
Signal Trans	2.00			2.00	
Carbon Resist	.80			.80	
Capacitor	2.00			2.00	
Ceramic Resistor	.50			.50	
PC Boards	2.00			2.00	
Conn and Pins	1.00			1.00	
Press Transducer	1.00			1.00	
Outer Shell	1.00			1.00	
Other	1.90			1.90	
Totals	18.00	15.50	6.20	39.70	

Based on current technology--not on LSI technology--LSI technology would probably be 30 to 50% less.

Electronic Control Unit

TOOLING COSTS

Amortization per Piece

Part	Economic Volume Per Year	1-Year Recurring Tooling	3-Year Non Recurring Tooling	12-Year Machinery Equipment	12-Year Launching Costs	40-Year Land & Buildings	Amortization Per Piece	
		.0100	.0100	.0625	.0062			Lean
ECU Unit	2,000,000	20,000	60,000	1,500,000	150,000	--	.0887	Burn

Electronic Control Unit

TOTAL MANUFACTURING COSTS

	Mat. Costs	Labor Costs	Over-Head	Mfg. (MC) Costs	Tooling	Corp. .20MC Alloc	Corp. .20MC Profit	Plant/ Vendor Costs
ECU	18.00	15.50	6.20	39.70	.0887	7.940	7.940	55.67
		21.70						

R & D - 2,000,000/year for 3 years for 2,000,000/year = 1.0000 R&D per vehicle.

Electronic Control Unit

RETAIL PRICE EQUIVALENT AT THE VEHICLE LEVEL

	Vendor/ Mfg. Costs (VC)	R&D	Tools and Equip	Corp Allocation .20 VC	Corp Profit .20 VC	Dealer Markup .40 VC	Vehicle Retail Price Equiv.
ECU Unit	55.67	1.00	--	11.13	11.13	22.27	101.21

This estimate is based on today's technology. Using learning curve data from the electronics industry, we can assume a 28% cost improvement for every doubled quantity. (Includes LSI technology).

Volume	RPE
2,000,000	101.21
4,000,000	72.87
8,000,000	52.47
16,000,000	37.78
32,000,000	27.20

Electronic Control Unit

AFTERMARKET ANALYSIS

The ECU units are being sold for $60 to $90 in the aftermarket with the VW unit at $222. The discount formula of ¼ computes the following:

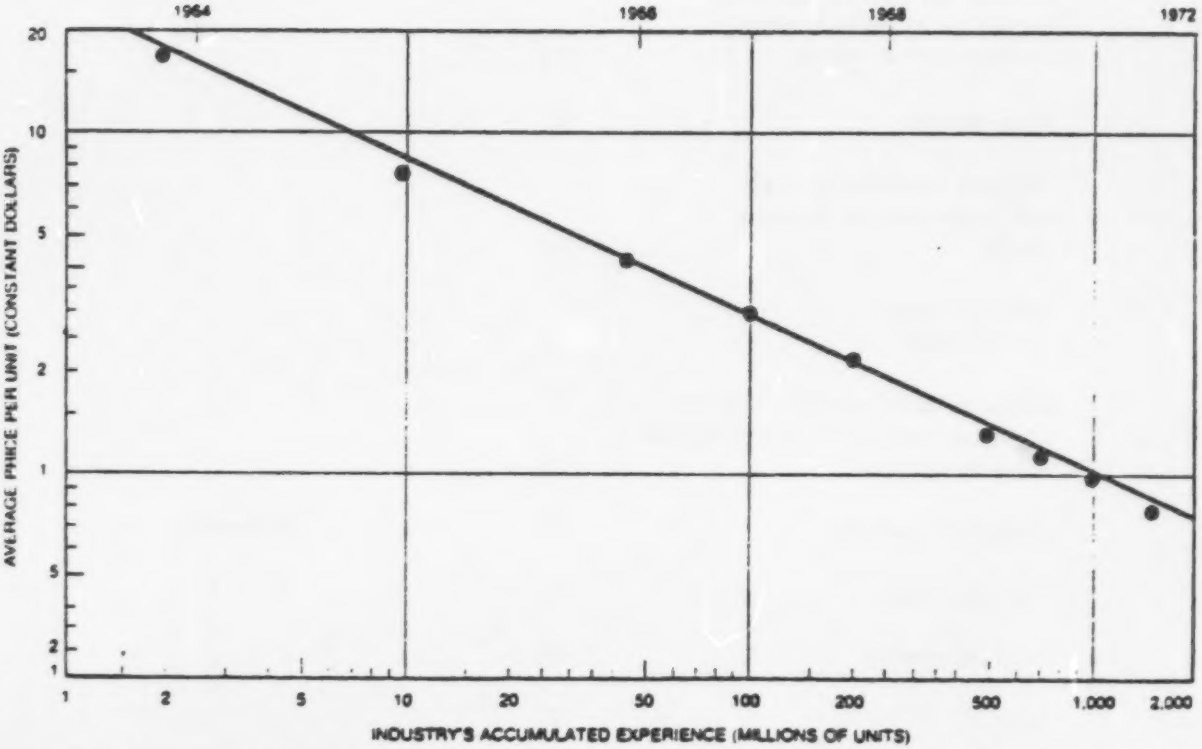
			1/4 Discount	
AFT	SP	$60.00	15.00	(modulator)
AFT	SP	90.00	25.00	(Ford modulator)
AFT	SP	222.00	55.50	(VW - ECU)

Electronic Control Unit

COST METHODOLOGY

The material cost data are estimates from a plant visitation. The tooling and process data were obtained from the same source.

COST METHODOLOGY



PRICES OF INTEGRATED CIRCUITS have conformed to an experience curve common to many industries, declining about 28 percent with each doubling of the industry's cumulative experience (as measured by the number of units produced). It is the particularly rapid growth of the microelectronics industry that has made the rate of decline in prices appear to be higher than the rate in other industries.

Fig. 1 Operational Flow Diagram

Operation		Remarks
Incoming Inspection	(10)	100% temperature test of all semiconductors
	Board 1 Board 2	
Automatic Component insertion	(15)	about 50 parts per board, 1 part per station
Individual semi-automatic insertion of power, semi-conductor & IC's	(7)	
Flow Solder	(2)	
1st unit test (parts test) and print out for trouble shoot	(2)	
2nd unit test (functional)	(2)	
Laser trim of ceramic resistor (trim to functional performance & trouble shoot)	(4)	
Automatic potting	(4)	Silicone
Post pat test	(2)	85° C
ECU Assembly	(6)	
Test	(2)	
Burn in	(2)	85°C 8 hrs
Test	(2)	Total production operators per shift (63)
Rack & Ship	(2)	+ undefined of 12 = 75 total

Table I

Test Equipment Estimate

Incoming Inspection	6 units at 40K each	$240,000
1st unit test - parts	2 units at 40K	80,000
2nd unit test	2 units plus computer	100,000
Laser resister term	1 unit	75,000
Post potting test	2 units at 25K	50,000
Burn in racks & test monitor	4 at 30,000	120.000
Total unit test	1 at 30,000	30,000
		695,000
	+ undefined	305,000
		1,000,000

Table II

Estimated Production Equipment

Automatic parts insertion	100 @ 1000 each	100,000
Parts insertion transport line	2 @ 20,000	40,000
Automatic Potting line	1 @ 50,000	50,000
Flow Soldex Machine (2 parallel lines in 1 machine)		30,000
Special stepping, assembly stations		100,000
		320,000
	other undefined	180,000
		500,000

APPLICATIONS

The variations in costs of ECU units will be dependent on the number of cylinders. The deltas will not be significant at this stage of technology.

IF - SENSORS, HEAVY DUTY GASOLINE ENGINES

1. Oxygen Sensor

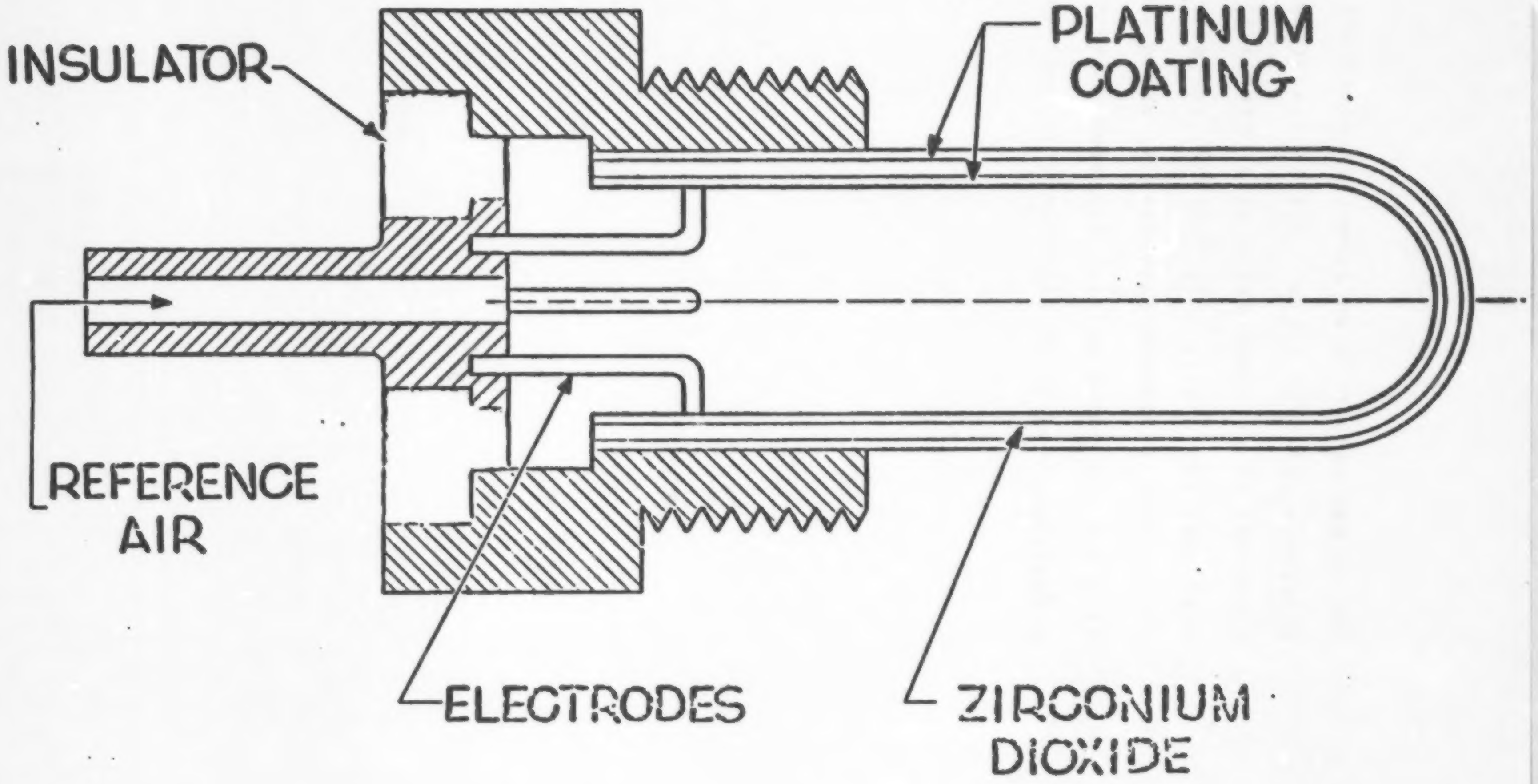
The detailed descriptions and calculations following this page apply to passenger car parts, reprinted from a previous report EPA - 78 - 002, March, 1978. The costs shown therein have been adjusted by using factors, described later in this report, that reflect differences in size and in manufacturing volume (economy of scale) between automobiles and trucks. The EOS used for automobiles is 350,000 per year; for trucks, 50,000.

The resulting retail price equivalent costs for trucks are shown below.

	Automobile Unit Cost	EOS Factor
Material	.484	1.3
Labor and Overhead	.131	2.7
Equipment	.090	2.4
Tooling	.033	3.4
Weighted EOS Factor		1.8
X Automobile Retail Price Equivalent		$2.78
= Truck Retail Price Equivalent		$5.00

The oxygen sensor is an essential component of most three-way catalyst systems and is used to maintain a control of air-fuel ratio at or near stoichiometric. With most catalysts, this "window" for effective performance is exceedingly narrow, being the order of ± 0.1 A/F ratio units. The oxygen sensor provides a feedback loop to an electronic control unit.

OXYGEN SENSOR


INSULATOR
PLATINUM COATING
REFERENCE AIR
ELECTRODES
ZIRCONIUM DIOXIDE

Bendix Electronic Fuel Injection Division

Oxygen Sensor

BILL OF MATERIAL

Part	Material	Weight	Mat Costs	Labor	Labor Over-Head	Mfg Costs	Reference
Oxygen Sensor	Assem	.100	-	.0312	.0125	.0437	Bendix
Air Inlet	Brass	.020	.0200	.0156	.0062	.0418	
Insulator	Plastic	.015	.0150	.0078	.0031	.0259	
Nut. Body	Brass	.050	.0500	.0156	.0062	.0718	
Electrodes	Copper	.005	.0100	.0078	.0031	.0209	
Zirconium Dioxide	ZrO_2	.010	.0500	.0078	.0031	.0609	
Platinum	Platin	.000016	.0397	.0078	.0031	.0506	See RHF 2/77
Total			.1847	.0936	.0373		
Hose		.100	.100	-	-	.1000	
Electric	Wire & Insulator	.200	.200	-	-	.2000	
Total Oxygen						.3156	
Vehicle Assem		-	-	.0312	.0125	.0437	
Engine Modification		-	-	.0625	.0250	.0875	ECU Unit
Total Vehicle Installation						.7468	

Oxygen Sensor System--Tooling Costs--Amortization Per Part

Part	Economic Volume	1 Year Recurring Tooling	3 Year Non-Recurring Tooling	12 Year Machinery & Equip	12 Year Launching Costs	40 Year Land & Buildings	Amortization Per Piece
Oxygen Sensor	5,000,000	.0100 50,000	.0050 75,000	.0020 120,000	.0002 12,000	-	.0172
Air Inlet	5,000,000	.0040 20,000	.0040 60,000	.0020 120,000	.0002 12,000		.0102
Insulator	5,000,000	.0040 20,000	.0040 60,000	.0020 120,000	.0002 12,000		.0102
Nut-Body	5,000,000	.0100 50,000	.0100 150,000	.0040 240,000	.0004 24,000		.0244
Electrodes	5,000,000	.0020 10,000	.0020 30,000	.0010 60,000	.0001 6,000		.0051
ZrO_2	5,000,000	.0020 10,000	.0020 30,000	.0010 60,000	.0001 6,000		.0051
Platinum	5,000,000	.0100 50,000	.0100 150,000	.0040 240,000	.0004 24,000		.0244
Total		.0420	.0370	.0160	.0016		.0966
Hose	5,000,000	.0040 20,000	.0017 25,000	.0025 150,000	.0002 15,000		.0084
Electric	5,000,000	.0040 20,000	.0017 25,000	.0025 150,000	.0002 15,000		.0084
Total System							
Vehicle Assem	300,000	.0167 5,000	.0333 30,000	.0056 20,000	.0006 2,000		.0562
Engine Modification	300,000	.0333 10,000	.0222 20,000	.0083 30,000	.0006 2,000		.0644
Total Vehicle Systems							.2340

R&D Estimates: $600,000 for 3 years, or .67 per vehicle for engineering development.

Oxygen Sensor System

TOTAL MANUFACTURING COSTS

Part	Mat	Labor	Plant Over-Head	Plant Mfg Costs	Tooling		.20 MC Corp	.20 MC Corp Profit	Mfg/ Vendor Costs
					Exp.	Inv.			
Oxygen Sensor	.1847	.0936	.0374	.3157	.0790	.0176	.0631	.0631	.5385
Hose	.100	-	-	.1000	.0057	.0027	.0200	.0200	.1484
Electric	.200	-	-	.2000	.0057	.0027	.0400	.0400	.2884
Total System									.9753

Oxygen Sensor System

RETAIL PRICE EQUIVALENT
AT THE VEHICLE LEVEL

Part	Plant Vendor Costs	R&D	Tools & Equip	Corp Alloc .20 VC	Corp Profit .20 VC	Dealer Markup .40 VC	Vehicle Retail Price Equivalent
Oxygen Sensor	.5385	.6667	-	.1077	.1077	.2154	1.6360
Hose	.1484	-	-	.0297	.0297	.0594	.2671
Electric	.2884	-	-	.0577	.0577	.1154	.5191
Vehicle Assem	.0437	-	.0562	.0087	.0087	.0175	.1349
Engine Mod	.0875	-	.0644	.0175	.0175	.0350	.2219
Total Vehicle Price Equivalent							2.7790

Oxygen Sensor System

Cost Comparison to Aftermarket Selling Prices

Using the aftermarket selling prices obtained from various company sources and aftermarket discount data, the following analysis is projected:

	Mathey Bishop M/B	Mercedes M/B
Oxygen Sensor	6.00	12.00
Discount 1/4	1.50	3.00
Discount 1/5	1.40	2.40

The estimated vendor costs are .5385. The retail price equivalent for the valve on the vehicle is 1.6360.

Oxygen Sensor System

Cost Methodology

The weight data was obtained using a Chrysler weight table for a spark plug. The material costs are compiled using the 1977 AMM mill prices.

The labor costs are estimates of production costs using today's technology and the assumed economies of scale. The platinum loading was obtained from EPA (Mr. Field) computations. The tooling costs are estimates of the expendable tools and the machinery and equipment required to produce the components.

The assembly costs and the engine changes were included in the costs at the vehicle level.

Oxygen Sensor System

Applications of the O_2 System

The Bendix and Bosch systems are similar designs. We have assumed that this sensor will not vary by engine size although it is possible that more than one sensor could be used in an electronically controlled three-way catalyst system.

HEAVY DUTY GASOLINE ENGINES

2. Spark Knock Sensor

The detailed descriptions and calculations following this page apply to passenger car parts, reprinted from a previous report EPA - 78 - 002, March, 1978. The costs shown therein have been adjusted by using factors, described later in this report, that reflect differences in size and in manufacturing volume (economy of scale) between automobiles and trucks. The EOS used for automobiles is 350,000 per year; for trucks, 50,000.

The resulting retail price equivalent costs for trucks are shown below.

Weighted EOS Factor	2.1
Automobile Retail Price Equivalent	\$60 - 90
Truck Retail Price Equivalent	\$126 - 189

Spark Knock Sensor (with piezo electric accelerometer or pickup)

The data for these systems are very limited at the time of this report. Detailed bills of material are not available so only a gross estimate is feasible. It is only a judgement cost estimate based on experience.

Spark Knock Sensor

The manufacturing costs of the knock sensor based on the schematic drawing indicates that a $40 to $60 cost will be a likely cost.

The RPE costs including the accelerometer is estimated to be $60 to $90 per unit.

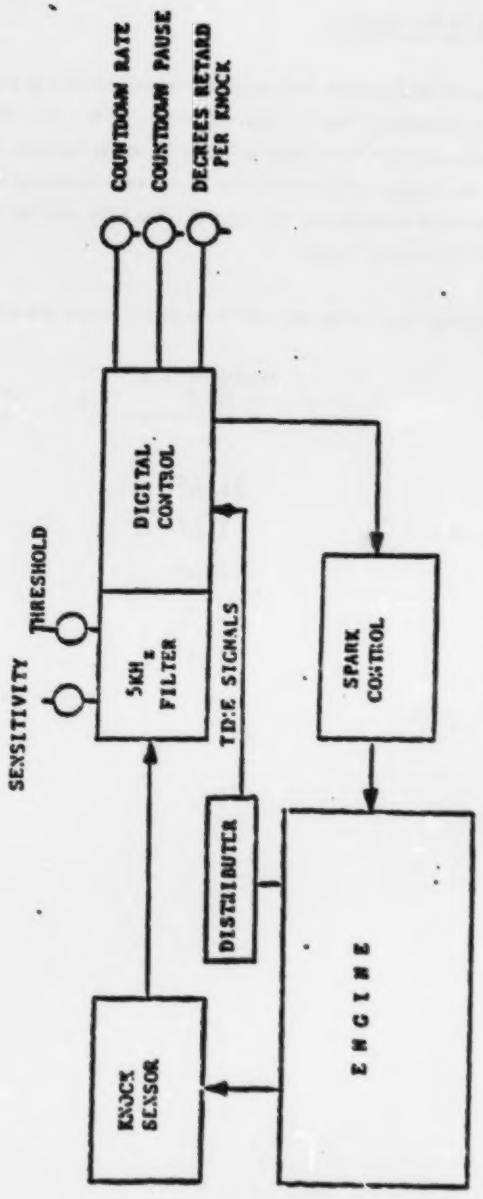
No aftermarket data are available at this date.

Further work is necessary to develop specific cost data.

KNOCK SENSOR
(Nonproduction Item)

ATTACHMENT III

KNOCK-SENSOR ACTUATED SPARK CONTROL

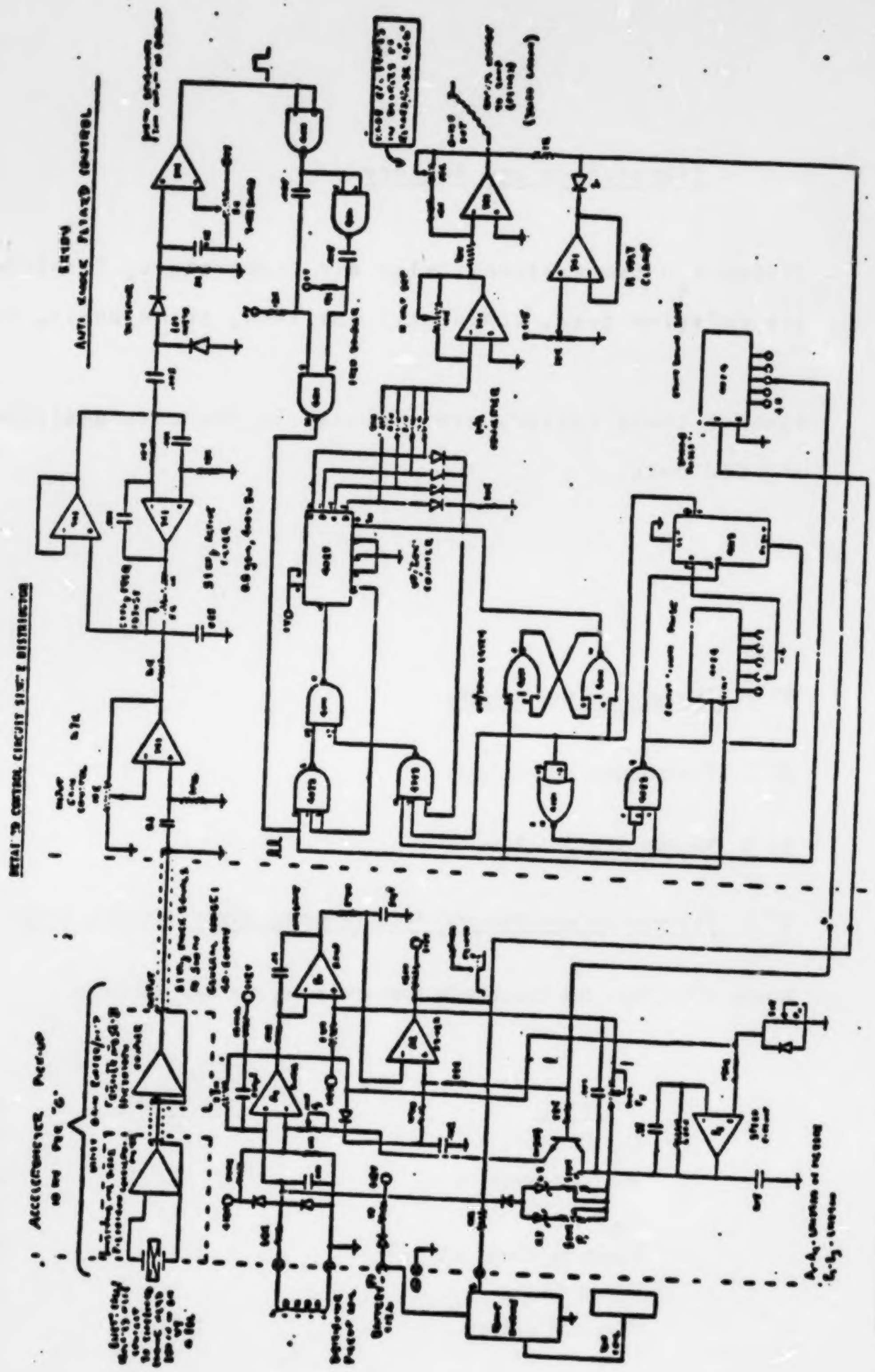

COUNTDOWN RATE
COUNTDOWN PAUSE
DEGREES RETARD PER KNOCK
DIGITAL CONTROL
THRESHOLD
SENSITIVITY
5KHz FILTER
TIME SIGNALS
SPARK CONTROL
DISTRIBUTER
ENGINE
KNOCK SENSOR

3. Sensors and Transducers

The detailed descriptions and calculations following this page apply to passenger car parts, reprinted from a previous report EPA - 78 - 002, March, 1978. The costs shown therein have been adjusted by using factors, described later in this report, that reflect differences in size and in manufacturing volume (economy of scale) between automobiles and trucks. The EOS user for automobiles is 350,000 per year; for trucks, 50,000.

The resulting retail price equivalent costs for trucks are shown below.

Sensor	Automobile RPE	x	EOS Factor	=	Truck RPE
Air Temperature	$1.67		2.1		$3.51
Water Temperature	1.67		2.1		3.51
Pressure Regulator	3.43		2.1		7.20
Speed	1.00		2.1		2.10
Throttle Switch	3.07		2.1		6.45



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Transducers and Sensors

(Types H_2O temperature, inlet air temperature, throttle position, transmission gear, EGR pintol position, crank angle, humidity.)

Some of these sensors are included in the cost analysis of EFI and ECU data.

37.1 Transducers and Sensors

37.2 Transducers and Sensors

37.3 Transducers and Sensors

37.4 Transducers and Sensors--Manufacturing Costs and RPE Costs

Using data from the Electronic fuel metering system , we have:

Sensor	5000 K Mfg./Vendor	RPE
O_2 Sensor	1.75	3.15
Air Temperature	.93	1.67
H_2O	.93	1.67
Pressure Regulator	1.91	3.43
Speed Sensor	.56	1.00
Throttle Switch	1.71	3.07

These data include tooling amortization.

Transducers and Sensors

The aftermarket cost comparison data are limited to foreign car data and are not useful for analysis.

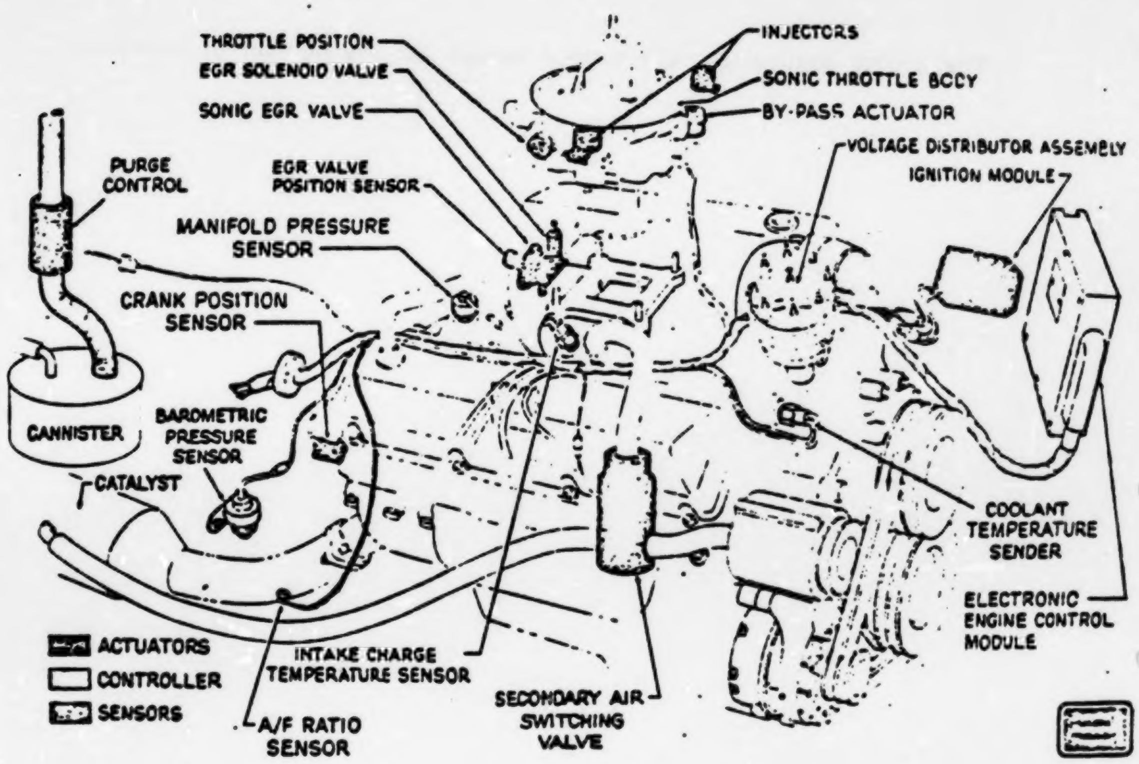
Transducers and Sensors

Cost Methodology. The learning curve analysis was used in these units.

Applications

The engine applications are similar except for the number of injectors.

ELECTRONIC ENGINE CONTROLS


THROTTLE POSITION
EGR SOLENOID VALVE
SONIC EGR VALVE
INJECTORS
SONIC THROTTLE BODY
BY-PASS ACTUATOR
VOLTAGE DISTRIBUTOR ASSEMBLY
IGNITION MODULE
PURGE CONTROL
EGR VALVE POSITION SENSOR
MANIFOLD PRESSURE SENSOR
CRANK POSITION SENSOR
CANNISTER
BAROMETRIC PRESSURE SENSOR
CATALYST
COOLANT TEMPERATURE SENDER
ELECTRONIC ENGINE CONTROL MODULE
ACTUATORS
CONTROLLER
SENSORS
INTAKE CHARGE TEMPERATURE SENSOR
SECONDARY AIR SWITCHING VALVE
A/F RATIO SENSOR

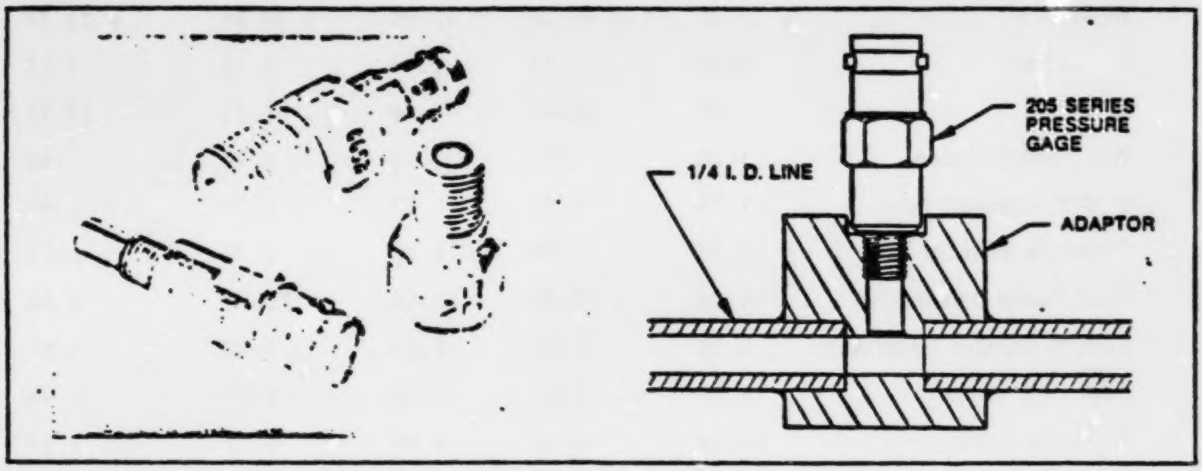
OEM COSTS--8-CYLINDER SYSTEM

	Industry Estimates			Projected Estimates	
Quantity	5 K	200 K	500 K	1,000 K	5,000 K
Injectors	$ 56.00	$ 40.00	$ 32.00	$ 29.25	$ 23.74
O_2 Sensor	6.00	4.50	2.36	2.16	1.75
ECU	75.00	45.00	45.00	41.13	33.39
Air Temperature	1.75	1.75	1.25	1.14	.93
H_2O Temperature	1.75	1.75	1.25	1.14	.93
Throttle Switch	3.00	3.00	2.30	2.10	1.71
Fuel Pump Assembly	15.00	15.00	12.00	10.97	8.90
Fuel Pressure Regulator	3.00	2.90	2.57	2.35	1.91
Fast Idle Valve	5.00	3.51	2.00	1.83	1.48
Throttle Body	10.00	8.78	5.00	4.57	3.71
Air Solenoid Valve	4.00	3.25	2.00	1.83	1.50
Fuel Filter	3.50	2.00	1.00	.91	.74
Fuel Rail	8.50	6.00	5.00	4.57	3.71
Speed Sensor	1.50	1.00	.75	.69	.56
Intake Manifold					
Wiring Harness	25.20	10.00	5.00	4.57	3.71
	$219.20	$148.44	$119.48	$109.21	$ 88.67

Sundstrand Data Control, Inc.
subsidiary of Sundstrand Corporation

Kistler Series
PIEZOTRON®
U.S. Patent No. 3,569,747

Hydraulic Pressure Gages



Features

- RUGGED & RELIABLE— 100,000,000 CYCLES
- SMALL SIZE—MOUNTS IN 1/4" LINES
- HIGH LEVEL OUTPUT— 5 VOLTS FULL SCALE
- HIGH RESOLUTION MEASURES 10,000 to 0.5 psi, or 1,000 to 0.05 with one sensor
- EASE OF INSTALLATION

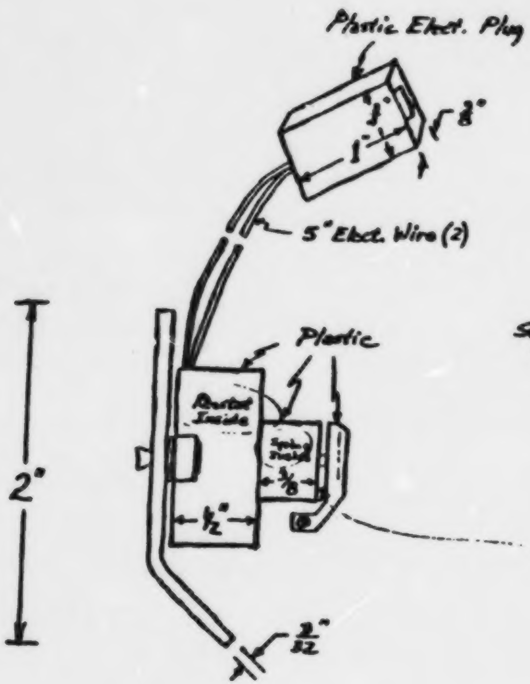
The 205 Series Hydraulic Pressure Gage was specifically designed FOR DYNAMIC HYDRAULIC PRESSURE MEASUREMENTS. Practically indestructible, with a hardened 17-4 PH stainless steel body, and tested for 100,000,000 cycles, they combine the stability, wide frequency response and high resolution of a quartz element with a high level output signal, compatible with most readout equipment. This is made possible with our revolutionary Piezotron concept whereby a miniature circuit is built into the housing to convert the quartz piezoelectric-generated charge to a robust, low impedance voltage.

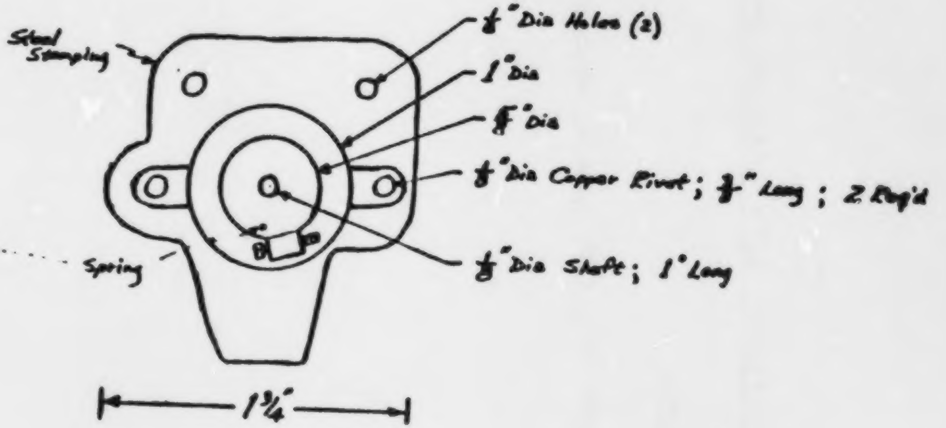
UNLIKE A STRAIN GAGE, the 205 Gages are designed for flush mounting in lines as small as 1/4" I.D., where its sensing surface "sees" the pressure changes you need to know, thereby eliminating cavitation effects. A truly dynamic instrument, with natural frequency of more than 250,000 Hz, IT DOESN'T MISS HALF YOUR DATA. A 25,000 to 1 signal-to-noise ratio with an output of 5 volts full scale allows you to read your whole dynamic pressure spectrum, accurately, with one sensor.

Designed to Measure Pump Ripple—Hydraulic Line Surges
Pipe Line Pulsations—Actuator Performance—Fuel Injection Pressure
Brake Systems Efficiency—Hydraulic Controls—Tubing Endurance

THROTTLE POSITION SENSOR

(APPROX. FULL SCALE)


Plastic Elect. Plug
$\frac{3}{8}$"
$\frac{1}{2}$"
1"
5" Elect. Wire (2)
Plastic
Reostat Inside
Spring Inside
$\frac{3}{8}$
$\frac{1}{2}$"
2"
$\frac{3}{32}$"


Steel Stamping
Spring
$\frac{1}{8}$" Dia Holes (2)
1" Dia
$\frac{5}{8}$" Dia
$\frac{1}{8}$" Dia Copper Rivet; $\frac{3}{8}$" Long; 2 Req'd
$\frac{1}{8}$" Dia Shaft; 1" Long
1$\frac{3}{4}$"

MAIN COMPONENT LIST

① STEEL MOUNTING PLATE ($\frac{3}{32}$" thick; 4 - ~$\frac{1}{8}$" holes; stamping)
② PLASTIC BODY (houses Reostat in large portion, Spring in smaller portion)
③ PLASTIC HUB + ARM (with threaded portion for adjustment screw); pressed on splined shaft)
④ STEEL ADJUSTMENT SCREW
⑤ STEEL RETURN SPRING
⑥ REOSTAT
⑦ STEEL SHAFT (splined on end for Arm/Hub; Reostat arm mounted on opposite end)
⑧ 2 - COPPER RIVETS
⑨ 2 - 5" ELECTRICAL WIRES WITH ATTACHED PLASTIC PLUG

IG - ACTUATORS--HEAVY DUTY GASOLINE ENGINE

1. EGR Valve Position Actuator

This is included in Section IB-1, EGR systems, representing 33% of the system.

IG - HEAVY DUTY GASOLINE ENGINE

2. Turbocharger Wastegate Position Actuator

This is a portion of the turbocharger estimate, Section IK.

3. Secondary Air Modulation, Vacuum Control

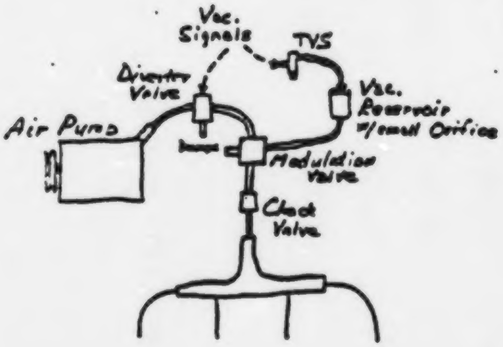
The detailed descriptions and calculations following this page apply to passenger car parts, reprinted from a previous report EPA - 78 - 002, March, 1978. The costs shown therein have been adjusted by using factors, described later in this report, that reflect differences in size and in manufacturing volume (economy of scale) between automobiles and trucks. The EOS used for automobiles is 350,000 per year; for trucks, 50,000.

The resulting retail price equivalent costs for trucks are shown below.

	Automobile Unit Costs	EOS Factor
Material	.460	1.3
Labor and Overhead	.574	2.7
Equipment	.027	2.4
Tooling	.152	3.4
	Weighted EOS Factor	2.3
X Automobile Retail Price Equivalent		$3.22
= Truck Retail Price Equivalent		$7.41

AIR MODULATION SYSTEM WITH VACUUM CONTROL

The air modulation system provides an appropriate volume of secondary air to the exhaust ports (or to a point between the 3-way catalyst and the oxidation catalyst) dependent upon both engine speed and load or, in other words, the volume of engine exhaust. This system attempts to more nearly match this air supply with engine needs for optimum oxidation of HC and CO while minimizing the cooling effect this air has on the exhaust gases. It consists of a diverter type valve that is actuated by a vacuum signal from intake manifold that in turn provides air to the exhaust stream.


Vac. Signals
TVS
Diverter Valve
Vac. Reservoir w/small Orifice
Air Pump
Modulation Valve
Check Valve

Air Modulation System

Same as air injection system except:

- *vac. line to TVS*
- *TVS*
- *vac. line to Vac. Res.*
- *Vac. Res. (same as above)*
- *vac. line from Vac. Res. to Mod. Valve*
- *Modulation Valve (same as diverter valve except with calibrated spring rate and more durable diaphragm)*

Air Modulation System

Tooling Costs--Amortization Per Part

Part	Economic Volume	1 Year Recurring Tooling	3 Year Nonrecurring Tooling	12 Year Machinery and Equipment	12 Year Launching Costs	40 Year Land and Building	Amortization Per Piece	Reference
Diverter Valve	2,500,000	.0580 145,000	.0580 435,000	.0167 500,000	.0017 50,000	-	.1343	6.2
Converter Hose	2,500,000	.0040 10,000	.0016 12,000	.0026 78,000	.0003 7,800		.0085	Diverter Valve
Vacuum Hose	2,500,000	.0004 1,000	.0002 1,500	.0003 7,800	.0001 3,000		.0010	Tooling Data
Air Manifold	2,500,000	.0200 50,000	.0100 75,000	.0050 120,000	.0005 12,000		.0355	"
Total		.0824	.0698	.0247	.0026		.1793	
Vehicle Assem.	500,000	-	-	-	-		-	
Engine Mod.	500,000	-	-	-	-		-	

Research and Development Estimate: $150,000 for 3 years, or $.1000 Per Piece

Air Modulation System
Bill of Material
Manufacturing Costs

Part	Material	Weight	Material Costs	Labor Costs	Labor Overhead	Manufacturing Costs	Reference
Diverter Valve	Steel	1.230	.3300	.3435	.1374	.8109	Sketch and
Converter Hose	Rubber	.500	.1000	.0312	.0125	.1437	EPA Data
Vacuum Hose	Rubber	.050	.0100	.0031	.0012	.0143	
Air Manifold	Steel	.100	.0200	.0312	.0125	.0637	
Total .						1.0326	
Vehicle Assem.			-	.0625	.0250	.0875	
Engine Mod.			-	.0156	.0062	.0218	
Vehicle Total						1.1419	

Air Modulation System--Total Manufacturing Costs

Part	Material	Labor	Plant Overhead	Plant Mfg. Costs	Tooling		Corp. Alloc. .20MC*	Corp. Profit .20MC*	Vendor Mfg. Costs
					Exp.	Inv.			
Diverter Valve	.3300	.3435	.1374	.8109	.1160	.0184	.1622	.1622	1.2697
Converter Hose	.1000	.0312	.0125	.1437	.0056	.0029	.0287	.0287	.2097
Vacuum Hose	.0100	.0031	.0012	.0143	.0006	.0004	.0029	.0029	.0210
Air Manifold	.0200	.0321	.0125	.0637	.0300	.0055	.0127	.0127	.1247
Total									1.6251

Air Modulation System Retail Price Equivalent At The Vehicle Level

Part	Plant Vendor Costs	R&D	Tools and Equip.	Corp. Alloc. .20VC*	Corp. Profit .20VC*	Dealer Markup .40VC*	Vehicle Retail Price Equivalent
Air Mod. System	1.6251	.1000	-	.3250	.3250	.6500	3.0252
Vehicle Assem.	.0875	-	-	.0175	.0175	.0350	.1575
Engine Mod.	.0218	-	-	.0044	.0044	.0087	.0392
Total RPE							3.2219

AIR MODULATION SYSTEM COST COMPARISON TO AFTERMARKET SELLING PRICES

An assumption was made that the air modulation valve would be similar to a diverter valve. (See E.P.A. sketch)

A diverter valve is priced at		$18.05
1/4 discount	=	4.51
1/5 discount	=	3.61

The RPE estimate is 3.0252 for the valve and the hoses. The manufacturing (vendor) estimate is 1.6251 for the valve and an added .1093 for the engine and assembly costs.

AIR MODULATION SYSTEM COST METHODOLOGY

The estimates were based on the diverter valve costs developed in the air injection section 6.0.

Other costs of the engine modifications and the assembly are estimates of the incremental changes required for this system.

AIR MODULATION SYSTEM APPLICATIONS TO VARIOUS ENGINES

No significant engine-to-engine costs are evident.

IH - THERMAL REACTOR
HEAVY DUTY GASOLINE ENGINE

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The resulting retail price equivalent costs for trucks are shown below.

		Automobile Unit Costs	EOS Factor
	Material	12.93	1.3
	Labor and Overhead	.52	2.7
	Equipment	.65	2.4
	Tooling	.43	3.4
	Weighted EOS Factor		1.5
X	Automobile Retail Price Equivalent		$37.62
=	Truck Retail Price Equivalent		$56.43

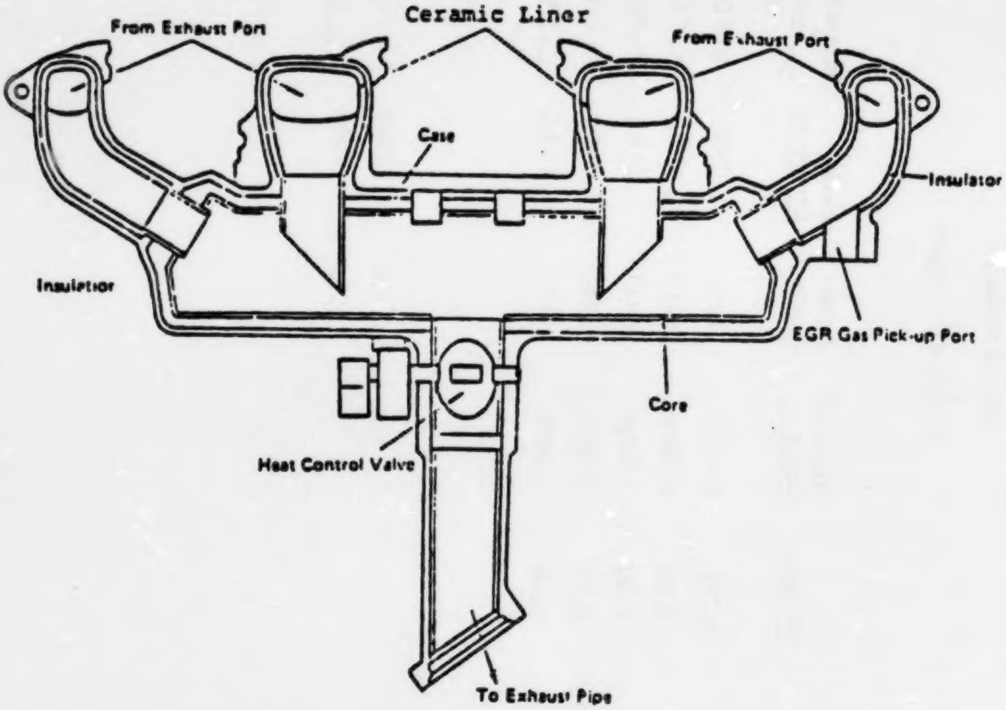
Thermal Reactor (Insulated With Core and Insulated Without Core)

Thermal reactors have been used to promote the gas-phase oxidation of hydrocarbons and carbon monoxide. Excess oxygen and high temperatures are required to insure efficient oxidation. Early versions have required a fuel-rich exhaust and air injection to insure that high thermal-reactor temperatures could be maintained. Such a system was particularly suited to the rotary engine because of its inherently high hydrocarbon exhaust levels. Unfortunately, the requirement to operate the engine fuel rich necessarily results in decreased fuel economy. Better design of the thermal-reactor system appears to allow use of a lean thermal reactor which would not suffer the fuel economy penalty of the rich thermal reactor. Air injection might still be required to insure that the oxidizing mixture is available at all engine operating conditions.

Many lean-burn engines also include a simple thermal reactor, often no more than a somewhat enlarged, thermally insulated exhaust manifold. Because of the lower exhaust temperatures of the lean-burn engines, thermal reactor performance is limited but usually adequate to give approximately a 50% reduction in hydrocarbons. Since the introduction of the oxidation catalyst, thermal reactors are now found primarily on rotary, lean-burn, and stratified-charge engines.

Thermal Reactor

Thermal Reactor Configuration


Ceramic Liner
From Exhaust Port
From Exhaust Port
Case
Insulator
Insulation
EGR Gas Pick-up Port
Core
Heat Control Valve
To Exhaust Pipe

Thermal Reactor Manufacturing Costs

Bill of Material

4-Cylinder Engine

Part	Material	Weight	Material Costs	Labor Costs	Labor Overhead	Manufacturing Costs	Reference
Exhaust Manifold	Cast Iron	14.75	4.4250	.1250	.0500	4.6000	.30/lb. EPA sketch
Liners	Ceramic	2.00	4.0000	.0413	.0165	4.0578	$2/lb.
Core Liners	H.T. Steel	2.00	2.0000	.0413	.0165	2.0578	$1/lb.
Core	H.T. Steel	3.00	2.0000	.1250	.0500	2.1750	$1/lb.
Insulation	Asbestos	1.00	.5000	.0413	.0165	.5578	$50/lb.
Total						13.4484	
Vehicle ASM				.1250	.0500	.1750	
Eng. Mod				.1250	.0500	.1750	
Total						13.7984	

Thermal Reactor Tooling Costs

Amortization Per Piece

Part	Economic Volume	1 Year Recurring Tooling	3 Year Nonrecurring Tooling	12 Year Machinery and Equipment	12 Year Launching Costs	40 Year Land and Building	Amortization per Per Piece
Exhaust Manifold	400,000	.1250 50,000	.1250 150,000	.5000 2,400,000	.0500 240,000	-	.8000
Liners	1,000,000	.0200 20,000	.0200 60,000	.0200 240,000	.0020 24,000	-	.0620
Core Liners	1,000,000	.0100 10,000	.0100 30,000	.0100 120,000	.0010 12,000	-	.0310
Core	400,000	.0500 20,000	.0500 60,000	.0500 240,000	.0050 24,000	-	.1550
Insulation	1,000,000	.0100 10,000	.0100 30,000	.0100 120,000	.0010 12,000	-	.0310
Total							1.0790
Vehicle ASM	400,000	.0250 10,000	.0250 30,000	.0250 120,000	.0025 12,000	-	.0775
Engine Mod	400,000	.0250 10,000	.0250 30,000	.0250 120,000	.0025 12,000	-	.0775

Research & Development - $400,000 per year for 3 years for 400,000 pieces per year or **$1.0000 per vehicle.**

Thermal Reactor Total Manufacturing Costs

Part	Material	Labor	Plant Overhead	Plant Mfg. Costs	Tooling Exp.	Tooling Inv.	Corp. Alloc. .20MC*	Corp. Profit .20MC*	Vendor Mfg. Costs
Exhaust Manifold	4.4250	.1250	.0500	4.6000	.2500	.5500	.9200	.9200	7.2400
Liners	4.0000	.0413	.0165	4.0578	.0400	.0220	.8116	.8116	5.7429
Core Liners	2.0000	.0413	.0165	2.0578	.0200	.0110	.4116	.4116	2.9119
Core	2.0000	.1250	.0500	2.1750	.1000	.0550	.4350	.4350	3.2000
Insulation	.5000	.0413	/0165	.5578	.0200	.0110	.1116	.1116	.8119
Total				13.4484					19.9067

*MC = Manufacturing Costs

Thermal Reactor Retail Price Equivalent

Part	Plant Vendor Costs	R&D	Tools and Equip.	Corp. Alloc. .20VC*	Corp. Profit .20VC*	Dealer Markup .40VC*	Vehicle Retail Price Equivalent
Thermal Reactor	19.9067	1.000	-	3.9813	3.9813	8/9627	36.8321
Vehicle	.1750		.0775	.0350	.0350	.0700	.3925
Engine Mod	.1750		.0775	.0350	.0350	.0700	.3925
Total							37.6171

The uninsulated thermal reactor costs are $35.37 excluding vehicle assembly and engine modifications.

*VC = Vendor Costs

Thermal Reactor Cost Comparison To Aftermarket Selling Prices

The Mazda Rotary Engines are selling the thermal reactors for $186.93 to $255.19 for RX-2 amd RX-3 engines. This selling price includes a five year warranty.

Using discount data:

	186.93	Est. Vendor Costs	Retail Price Equivalent
Discount 1/4	46.73		
Discount 1/5	37.40	19.83	37.49

The exhaust manifold on a CVCC Honda sells for $79.20. Using the discount formula, the vendor cost is 79.20 ÷ 4 = $19.80.

Thermal Reactor Cost Methodology

The weight data are estimates based on 4 cylinder exhaust data. The material costs are estimates based on material selections.

The design data are from the sketch in 19.0.

II - IGNITION SYSTEMS
HEAVY DUTY GASOLINE ENGINE

1. Breaker Point Ignition System

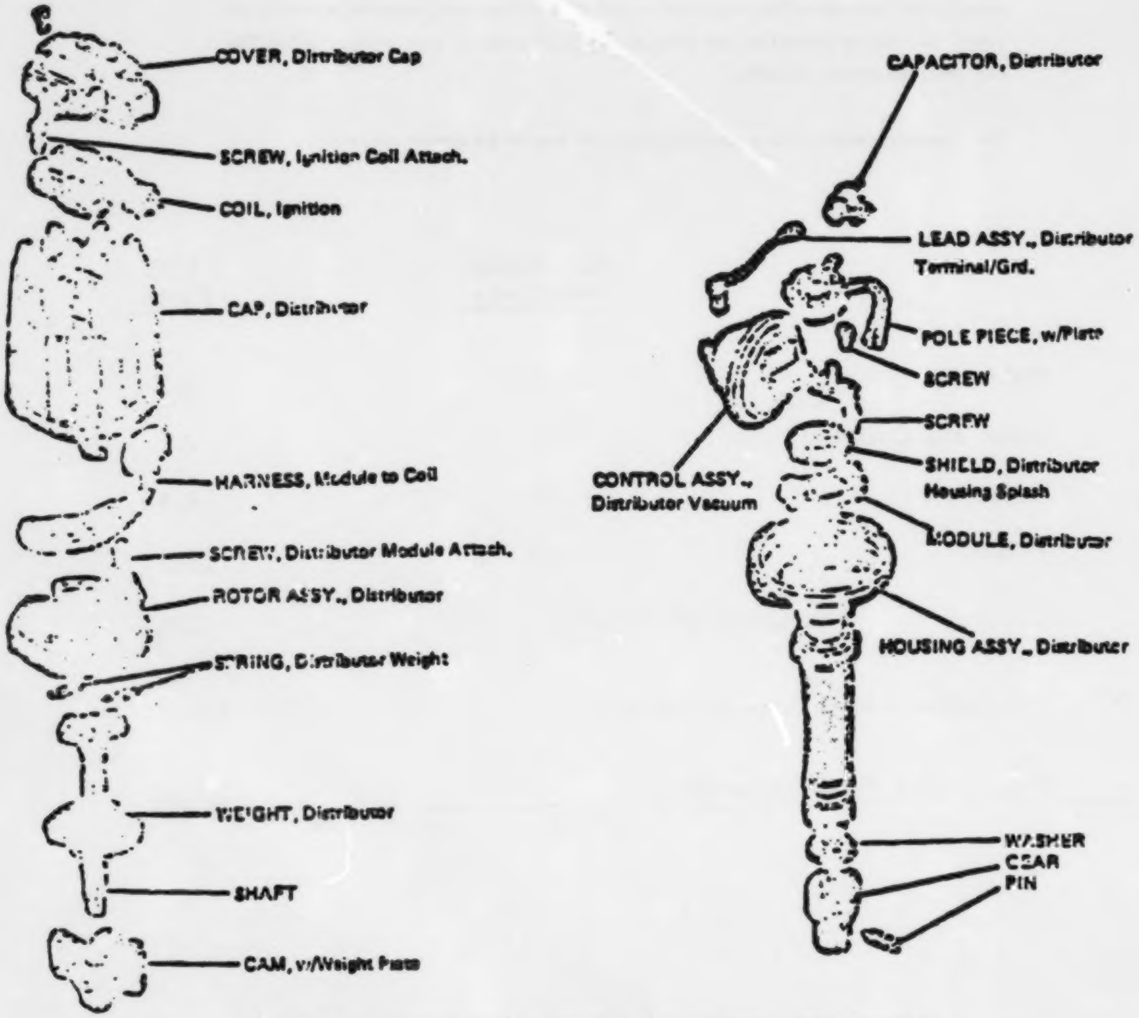
The detailed descriptions and calculations following this page apply to passenger car parts, reprinted from a previous report EPA - 78 - 002, March, 1978. The costs shown therein have been adjusted by using factors, described later in this report, that reflect differences in size and in manufacturing volume (economy of scale) between automobiles and trucks. The EOS used for automobiles is 350,000 per year; for trucks, 50,000.

The resulting retail price equivalent costs for trucks are shown below.

		Automobile Unit Costs	EOS Factor
	Material	2.35	1.3
	Labor and Overhead	6.41	2.7
	Equipment	.09	2.4
	Tooling	.33	3.4
	Weighted EOS Factor		2.4
X	Automobile Retail Price Equivalent		$23.28
=	Truck Retail Price Equivalent		$55.87

Breakerpoint Ignition System

The breakerpoint distributor has been the mainstay of ignition systems. The advent of the emissions requirements created the need for improved designs such as the electronic igition system defined in 26.0.


COVER, Distributor Cap
SCREW, Ignition Coil Attach.
COIL, Ignition
CAP, Distributor
HARNESS, Module to Coil
SCREW, Distributor Module Attach.
ROTOR ASSY., Distributor
SPRING, Distributor Weight
WEIGHT, Distributor
SHAFT
CAM, w/Weight Plate
CAPACITOR, Distributor
LEAD ASSY., Distributor Terminal/Grd.
POLE PIECE, w/Plate
SCREW
SCREW
SHIELD, Distributor Housing Splash
CONTROL ASSY., Distributor Vacuum
MODULE, Distributor
HOUSING ASSY., Distributor
WASHER
GEAR
PIN

Exploded view of H.E.I. distributor (Typical). All except Cadillac with fuel injection

Reproduced from best available copy.

Breakerpoint Ignition System

MANUFACTURING COSTS

Bill of Material

Part	Mat.	Weight	Mat. Costs	Labor Costs	Overhead Labor Costs	Mfg. Plant Costs
Distributor Assembly	Plastic Steel	2.000	1.000	2.800	1.1200	4.9200
Cap	Plastic	.150	.1200	.3500	.1400	.6100
Rotor	Plastic Copper	.050	.0100	.1000	.0400	.1500
Breakerpoints	Copper	.010	.0080	.1200	.0480	.1760
Condenser	Plastic Copper	.050	.0400	.1100	.0440	.1940
Vacuum Control	Steel Copper	.200	.1000	.3500	.1400	.5900
Ignition Coil	Copper Plastic	1.780	1.0680	.7500	.3000	2.1180
Total						8.7580

Breakerpoint Ignition System

TOOLING COSTS

Amortization per Piece

Part	Economic Volume Per Year	1-Year Recurring Tooling	3-Year Non Recurring Tooling	12-Year Machinery Equipment	12-Year Launching Costs	40-Year Land & Buildings	Amortization Per Piece
Distributor Assembly	1,000,000	.0500 50,000	.0500 150,000	.0500 600,000	.0050 60,000	--	.1550
Cap	1,000,000	.0100 10,000	.0100 30,000	.0100 120,000	.0010 12,000	--	.0310
Rotor	1,000,000	.0050 5000	.0100 30,000	.0050 60,000	.0005 6000	--	.0205
Breakerpoints	1,000,000	.0050 5000	.0100 30,000	.0050 60,000	.0005 6000	--	.0205
Conderser	1,000,000	.0300 30,000	.0300 90,000	.0050 60,000	.0005 6000	--	.0655
Vacuum Contl	1,000,000	.0300 30,000	.0300 90,000	.0050 60,000	.0005 6000	--	.0655
Ignition Coil	1,000,000	.0300 30,000	.0300 90,000	.0050 60,000	.0005 6000	--	.0655
Total							.4235

Breakerpoint Ignition System

TOTAL MANUFACTURING COSTS

Part	Mat	Labor	Plant Over-Head	Plant Mfg Costs (MC)	Tooling Exp.	Tooling Inv.	.20/MC Corp. Alloc.	.20/MC Corp. Profit	Mfg/ Vendo Costs
Dist. Assembly	1.000	2.8000	1.1200	4.9200	.1000	.0550	.9840	.9840	7.0430
Cap	.1200	.3500	.1400	.6100	.0200	.0110	.1220	.1220	.8850
Rotor	.0100	.1000	.0400	.1500	.0150	.0055	.0300	.0300	.2305
Breaker Points	.0080	.1200	.0480	.1760	.0150	.0055	.0352	.0352	.2669
Condenser	.0400	.1100	.0440	.1940	.0600	.0055	.0388	.0388	.3371
Vacuum Coil	.1000	.3500	.1400	.5900	.0600	.0055	.1180	.1180	.8915
Ignition Coil	1.0680	.7500	.3000	2.1180	.0600	.0055	.4236	.4236	3.0307
Total				8.7580					12.6847

Breakerpoint Ignition System

RETAIL PRICE EQUIVALENT AT THE VEHICLE LEVEL

	Vendor Costs (VC)	R&D	Tools and Equip	Corp Allocation .20 VC	Corp Profit .20 VC	Dealer Markup .40 VC	Vehicle Retail Price Equiv.
Dist. System	12.6847	--	--	2.5369	2.5369	5.0739	22.8325
Vehicle Assy	.2500	--	--	.0500	.0500	.1000	.4500
Total RPE							23.2825

Breakerpoint Ignition System

Group 2 (Chilton)
Ignition System (Chrysler data)
Aftermarket Selling Price Analysis

	Breakerless Distribution Assembly 1972 Data	High Energy Ignition 1977 Data Total Assembly
Six Cyl	39.80	45.00
8 Cyl 318	46.25	47.55
8 Cyl 400	53.15	54.75

	Breakerless Distribution Assembly 1972 Data		High Energy Ignition 1977 Data	
	6 Cyl	8 Cyl	6 Cyl	8 Cyl
Distribution Cap	4.25	4.85	3.81	4.85
Points	3.30	3.30	--	--
Condenser	1.60	1.60	--	--
Dist Lead Wires	.82	.82	--	--
Rotor	1.25	1.25	1.92	1.92
Reluctor	--	--	1.92	1.92
Pick up and Plate	--	--	13.45	13.45
Breaker Plates	10.50	10.50	--	--
Vacuum Control Unit	5.35	5.35	5.35	5.35
Coil	14.92	14.92	--	--
Resistors	2.55	2.55	--	--
Governor Shaft Assembly	14.95	14.95	14.95	14.95
Dist Housing	6.07	8.69	6.07	8.69

Breakpoint Ignition System
Analysis of Aftermarket Selling Prices
Group 2 (Chilton) G. M. Data

Breakerless Assembly (1972 car data)			Electronic Ignition (1977 car data)		
	6 Cyl	8 Cyl		6 Cyl	8 Cyl
Distributor Assembly	54.05	58.30	(Total Distributor)	138.75	170.50
Points	3.68	5.60		-	-
Condenser	1.71	1.71		-	-
Rotor	1.35	2.31		3.65	3.90
Cap	4.07	6.55	Cap	8.63	11.65
			Cover	3.09	3.09
Coil	16.40	16.40	Coil	32.90	27.80
Breaker Plate	3.00	3.29	Pole Piece & Plate	20.70	20.70
Vacuum Control	4.02	4.02		5.85	5.85
Shaft (Included in Assy.)	23.50	23.50		23.50	23.50
Capacitor	-	-		2.67	2.67
Module	-	-		15.70	53.10
Housing	Included	Item 1		14.90	20.25
Harness	-	-		9.80	9.80
Total	111.78	121.68			
Less Shaft	23.50	23.50			
	88.28	98.18		138.75	170.50

Breakerpoint Ignition System

COST METHODOLOGY

The weight data was obtained from Chrysler data. The cost estimates are gross; not based on a part by part operational analysis.

The analysis of various systems--breakerpoint versus electronic--provides a top down reference cost.

Breakerpoint Ignition System

APPLICATIONS

Using the aftermarket data, the delta difference by engine size is proportional to the number of cylinders.

HEAVY DUTY GASOLINE ENGINES

2. High Energy (Electronic) Ignition System

The detailed descriptions and calculations following this page apply to passenger car parts, reprinted from a previous report EPA - 78 - 002, March, 1978. The costs shown therein have been adjusted by using factors, described later in this report, that reflect differences in size and in manufacturing volume (economy of scale) between automobiles and trucks. The EOS used for automobiles is 350,000 per year; for trucks, 50,000.

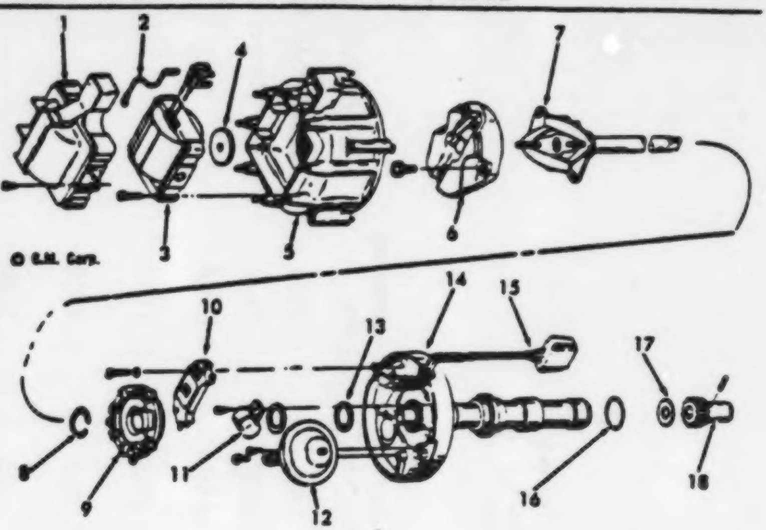
The resulting retail price equivalent costs for trucks are shown below.

		Automobile Unit Costs	EOS Factor
	Material	2.68	1.3
	Labor and Overhead	17.45	2.7
	Equipment	.28	2.4
	Tooling	.62	3.4
	Weighted EOS Factor		2.5
X	Automobile Retail Price Equivalent		$53.13
=	Truck Retail Price Equivalent		$132.83

Group 2 - ELECTRONIC IGNITION - Parts

	Part No.	Price
Distributor Assy.		
Chevrolet		
(250 eng)		
1977—w/A.T.	♦1112863	138.75
w/M.T.	♦1110666	140.00
(305 eng)		
1977—exc below	1112977	170.50
Calif w/A.T.	1112999	180.00
(350 eng)		
1975-77	1112880	170.50
(400 eng)		
1974—2 bbl	1112866	180.00
4 bbl	1112865	180.00
1975-76	1112882	180.00
(454 eng)		
1974—2 bbl (Calif.)	1112527	170.50
1975-76	1112886	170.50
Corvette		
1975—exc below	1112888	170.50
w/Sp hi perf	1112883	180.00
Calif.	1112959	172.25
1976-77—exc below	1103200	180.00
w/A.T.	1112979	180.00

	Part No.	Price
(1) Cover		
1974-77	♦1875960	3.09
(2) Lead Assy.		
1974-77	♦1876155	.58
(3) Coil		
1974-77—exc below	♦1875894	27.80
1977—250 eng.	♦1115444	32.90
(4) Seal		
1974-77	♦1875962	2.51
(5) Cap		
1974-77—exc below	♦1875963	11.65
1977—250 eng.	♦1880042	8.63
(6) Rotor		
1974	♦1891080	3.65
1975-77—exc below	♦1891080	3.65
1977—250 eng.	♦1892562	3.90



	Part No.	Price
(7) Shaft		
Chevrolet		
(250 eng)		
1977—exc below	1891145	23.50
w/Int cyl hd	♦1891100	23.30
(w/1110166 dist)	♦1892542	25.00
(305 eng)		
1977	1892078	27.00
(350 eng)		
1975-76	830072	23.50
(400 eng)		
1974—2 bbl	1880113	23.50
4 bbl	1880115	23.50
sta wag	1876324	23.50
(454 eng)		
1974—2 bbl (Calif.)	1876404	23.50
1975-77	830121	23.50
Corvette		
1975-77—exc below	830165	23.50
Sp hi perf	830110	23.50

	Part No.	Price
1975—Calif.	1891294	23.50
1976—w/Sp hi perf		
Calif.	1891719	23.50
(8) Retainer		
Chevrolet		
1974-77	♦830446	.25
Corvette		
1975-77	N.L.	. . .
(9) Pole Piece & Plate Assy.		
1974-77	♦1875981	20.70
(10) Module		
1974-77—exc below	♦1875990	53.10
1977—250 eng.	♦1880040	15.70
(11) Capacitor		
1974-77	♦1876154	2.67

	Part No.	Price
(12) Vacuum Control		
Chevrolet		
(250 eng)		
1977—exc below	♦1973550	5.50
w/Int cyl hd	♦1973517	5.85
(305, 350 engs)		
1977	♦1973517	5.85
(400 eng)		
1974—sta wag		
w/4 bbl	1973507	5.85
1975-76	1973492	5.85
(454 eng)		
1975-76	♦1973517	5.85
Corvette		
1975-77—exc below	1973482	4.48
w/Dist no. (1112888)	♦1973517	5.85
1976-77—350 eng (Calif.)		
w/Sp hi perf	1973508	5.85
[illegible]	[illegible]	[illegible]

	Part No.	Price
(13) Seal		
1974-77	♦1950569	.09
(14) Housing		
1974-77—exc below	1876222	20.25
1977—250 eng.	♦1880038	14.90
(15) Harness		
1974-77—exc below	♦1876018	9.80
1977—250 eng.	♦1880021	9.80
(16) Washer		
1975-77	♦1837617	.07
(17) Washer		
1974-77	♦1965864	.41
(18) Gear		
1974-77—exc below	♦1958599	5.35

	Part No.	Price
1977—250 eng		
w/Int cyl hd	♦1955676	9.00
wo/Int cyl hd	♦1962062	5.15
Ignition Wires		
Chevrolet		
(350, 400 engs)		
1974-76	♦8908551	42.73
(454 eng)		
1974 (Calif.)	8919646	43.15
1975-76	8919646	43.18
Corvette		
1975-77	8908567	45.80
Ignition Switch		
1974-77—exc below	♦1990096	6.15
tilt whl	♦1990099	6.90

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High Energy Ignition System
Manufacturing costs
Bill of Material

Part	Material	Weight	Material Costs	Labor Costs	Labor Overhead	Manufacturing Costs	Reference
Distrib. Asm.	-	2.000	-	.3500	.1400	.4900	Electronic test
Cap	Plastic	.200	.1600	.4000	.1600	.7200	See sketch
Cover	Plastic	.100	.0800	.1500	.0600	.2900	
Coil	Copper Plastic	.200	.1600	2.2500	.9000	3.3100	
Pole Pc & Plastic	Copper Iron	.100	.0800	1.2500	.5000	1.8300	
Vacuum Cont	Steel Copper	.200	.1000	.8500	.3400	1.2900	
Shaft	Steel	.3000	.1200	.7500	.3000	1.1700	
Capacitor	Plastic Copper	.1000	.5000	.5000	.2000	1.2000	
Module	Copper Plastic Ceramic	.2000	1.0000	4.0000	1.6000	6.6000	
Housing	Plastic	.4000	.3200	.7500	.3000	1.3700	
Harness	Copper	.2000	.1600	.5000	.2000	.8600	
						19.1300	

High Energy Ignition System

Tooling Costs

Amortization Per Piece

Part	Economic Volume	1 Year Recurring Tooling	3 Year Nonrecurring Tooling	12 Year Machinery and Equipment	12 Year Launching Costs	40 Year Land and Building	Amortization Per Piece
Distrib. Assem.	1,000,000	.0500 50,000	.0500 150,000	.0500 600,000	.0050 60,000		.1550
Cap	1,000,000	.0200 20,000	.0200 60,000	.0200 240,000	.0020 24,000		.0620
Cover	1,000,000	.0100 10,000	.0100 30,000	.0100 120,000	.0010 12,000		.0310
Coil	1,000,000	.0300 30,000	.0300 90,000	.0050 60,000	.0005 6,000		.0655
Pole Pc & Plate	1,000,000	.0300 30,000	.0300 90,000	.0050 60,000	.0005 6,000		.0655
Vacuum Cont	1,000,000	.0500 50,000	.0500 150,000	.0500 600,000	.0050 60,000		.1550
Shaft	1,000,000	.0200 20,000	.0200 60,000	.0100 120,000	.0010 12,000		.0510
Capacitor	1,000,000	.0100 10,000	.0100 30,000	.0100 120,000	.0010 12,000		.0310
Module	1,000,000	.0500 50,000	.0500 150,000	.1000 1,200,000	.0100 120,000		.2100
Housing	1,000,000	.0300 30,000	.0300 90,000	.0300 360,000	.0030 36,000		.0930
Harness	1,000,000	.0100 10,000	.0100 30,000	.0100 120,000	.0010 12,000		.0310
						Total	.9500

R&D 1,500,000/year for 3 years for 1,000,000 units per year or $1.50 per piece.

High Energy Ignition System

Total Manufacturing Costs

Part	Material	Labor	Plant Overhead	Plant Mfg. Costs	Tooling		Corp. Alloc. .20MC*	Corp. Profit .20MC*	Vendor Mfg. Costs
					Exp.	Inv.			
Dist. Assem.	-	.3500	.1400	.4900	.1000	.0550	.0980	.0980	.8410
Cap	.1600	.4000	.1600	.7200	.0400	.0220	.1440	.1440	1.0700
Cover	.0800	.1500	.0600	.2900	.0200	.0110	.0580	.0580	.4370
Coil	.1600	2.2500	1.9000	4.3100	.0600	.0055	.6620	.6620	5.6995
Pole Pc & Plate	.0800	1.250	.5000	1.8300	.0600	.0055	.3660	.3660	2.6275
Vacuum Cont	.1000	.8500	.3400	1.2900	.1000	.0055	.2580	.2580	1.9115
Shaft	.1200	.7500	.3000	1.1700	.0400	.0110	.2340	.2340	1.6890
Capacitor	.5000	.5000	.2000	1.2000	.0200	.0110	.2400	.2400	1.7110
Module	1.0000	4.0000	1.6000	6.6000	.1000	.1100	1.3200	1.3200	9.4500
Housing	.3200	.7500	.3000	1.3700	.0600	.0330	.2740	.2740	2.0110
Harness	.1600	.5000	.2000	.8600	.0200	.0110	.1720	.1720	1.2350
				20.1300					28.6825

High Energy Ignition System

Retail Price Equivalent at the Vehicle Level

Part	Plant Vendor Costs	R&D	Tools and Equip.	Corp. Alloc. .20VC*	Corp. Profit .20VC*	Dealer Markup .40VC*	Vehicle Retail Price Equivalent
HE Ignition	28.6825			5.7365	2.7365	11.4730	53.1285

High Energy Ignition System

Cost Comparison to Aftermarket Selling Prices

The manufacturing vendor costs for the system is $ 27.6825. Using the 4 to 1 Discount the estimated aftermarket comparison price is $117.7428. The Chilton price for this system can vary between $138.75 for the 6 cylinder to $170.56 for 8 cylinder engines.

High Energy Ignition System

Cost Methodology

The weight data and material costs are estimates. The labor costs are estimates for a given economy of scale (1,000,000 units/year). The bill of material data was limited to the G.M. Chilton data.

High Energy Ignition System

Applications

The applications of these costs to engines will be proportional to the number of cylinders per engines.

IK - TURBOCHARGER
HEAVY DUTY GASOLINE ENGINES

The detailed descriptions and calculations following this page apply to passenger car parts. The costs shown therein have been adjusted by using factors, described later in this report, that reflect differences in size and in manufacturing volume (economy of scale) between automobiles and trucks. The EOS used for automobiles is 350,000 per year; for trucks, 50,000.

The resulting retail price equivalent costs for trucks are shown below.

Automobile Unit Costs

	100HP	220HP	250HP	350HP	450HP	EOS Factor
Material	8.98	20.21	21.89	23.57	24.13	1.3
Labor & O.H.	7.57	13.25	14.10	14.95	15.23	2.7
Equipment	.94	.94	.94	.94	.94	2.4
Tooling	.66	.66	.66	.66	.66	3.4
Weighted EOS Factors	2.0	1.9	1.9	1.9	1.9	
X Auto RPE	46.47	88.70	95.09	101.45	103.56	
= Truck RPE	92.94	168.53	180.67	192.76	196.76	

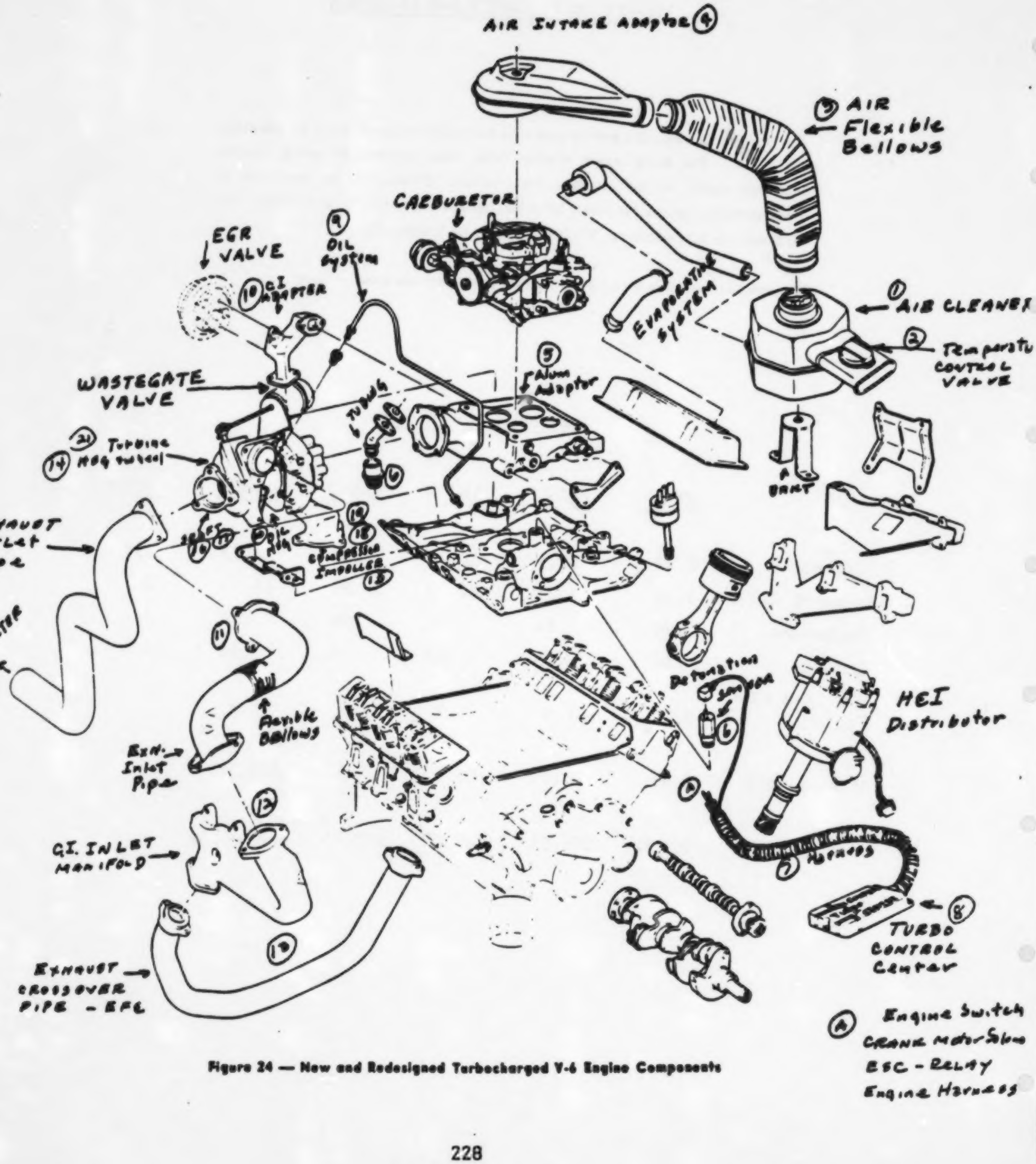
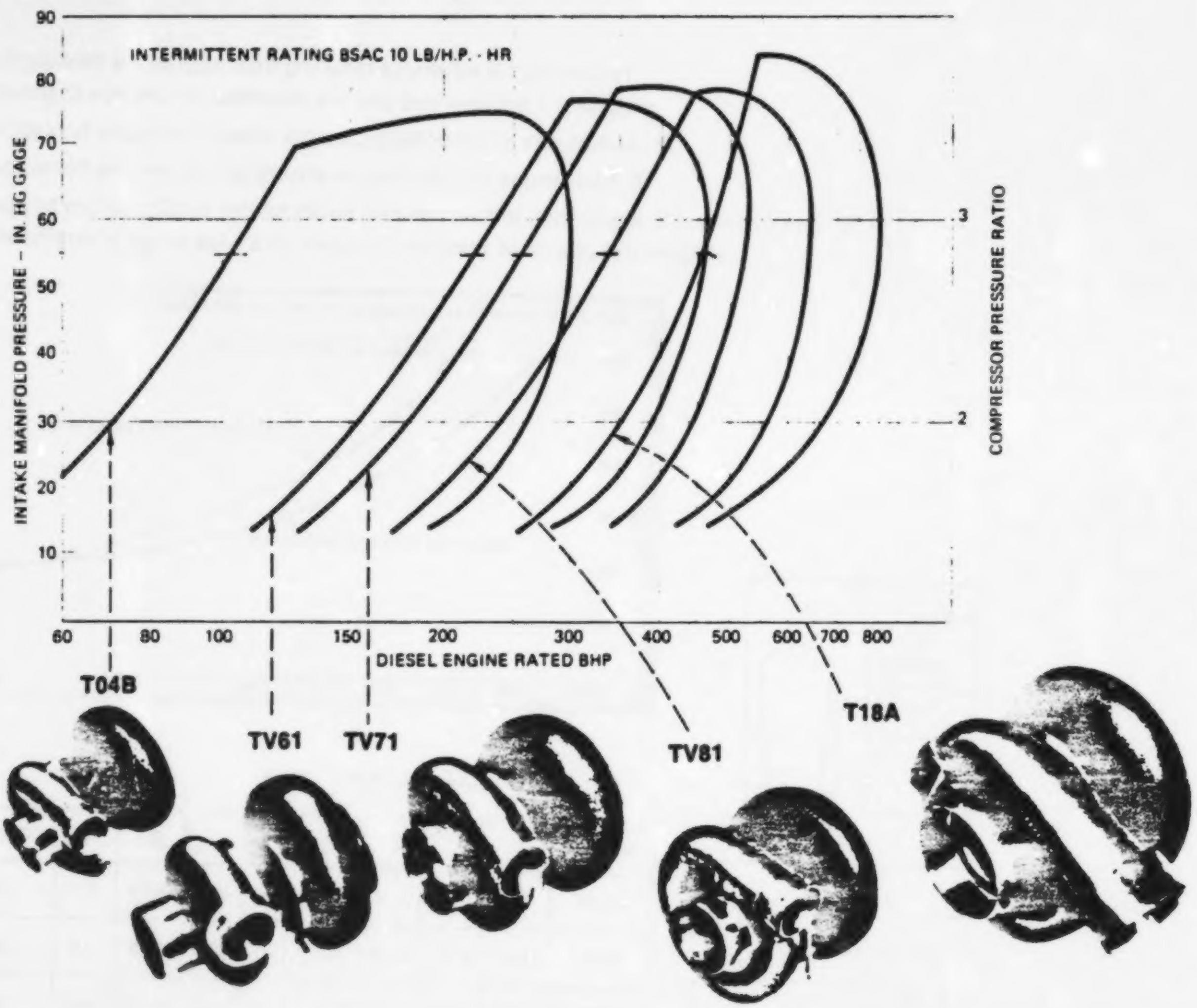

AIR INTAKE Adaptor ④
③ AIR Flexible Bellows
CARBURETOR
⑨ OIL System
EGR VALVE
⑩ G.I. ADAPTER
WASTEGATE VALVE
Tubing
⑤ Alum Adaptor
EVAPORATIVE SYSTEM
① AIR CLEANER
② Temperature CONTROL VALVE
㉑ ⑭ Turbine Hsg wheel
⑥
A BRKT
Exhaust Outlet Pipe
⑲
⑱
Oil Hsg
Compression Impeller ⑮
CONVERTER
⑪
Flexible Bellows
Exh. Inlet Pipe
⑫
G.I. INLET MANIFOLD
⑬
Exhaust CROSSOVER PIPE - EFE
Detonation Sensor
⑥
HEI Distributor
⑦ Harness
⑧ TURBO CONTROL CENTER
Ⓐ Engine Switch
CRANK Motor Soleno
ESC - RELAY
Engine Harness

Figure 24 — New and Redesigned Turbocharged V-6 Engine Components

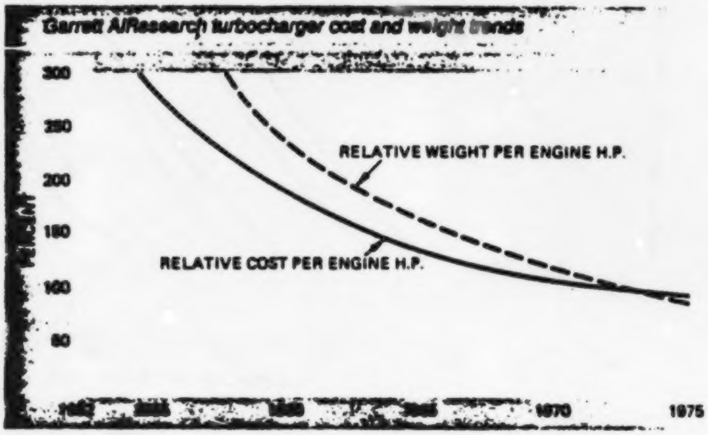
Engine Coverage With AiResearch Turbocharger Models

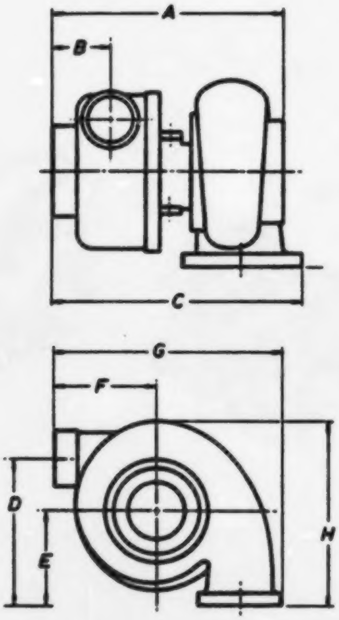


Technological advances resulting from aggressive development programs have provided and are expected to continue to provide:

- Reductions in turbocharger weight relative to engine horsepower
- Reductions in turbocharger cost relative to engine horsepower
- Improvements in application techniques and turbocharger configurations to permit efficient use of a small number of models on a wide range of engine sizes

Garrett AIResearch turbocharger cost and weight trends





Dimensions are in inches

MODEL	A	B	C	D	E	F	G	H	POUNDS
T04B	7.43	1.50	8.23	5.25	3.00	4.35	8.73	6.3	16
TV61	12.07	3.10	12.46	7.34	4.25	5.50	10.93	9.0	36
TV71	10.93	1.96	11.33	7.34	4.25	5.50	10.93	9.50	39
TV81	10.93	1.96	11.33	7.34	4.25	5.50	10.93	10.0	42
T18A	11.25	2.50	11.25	9.25	4.25	5.75	12.00	10.0	43

TURBOCHARGER
TO3
MANUFACTURING COST

Component	Weight	Material	Material Costs	Labor Hrs.	Labor	Overhead 40%	Mfg. Costs
Turbocharger Assem.	17.00	-	-	.067	.5025	.2010	.7035
Turbine Wheel	.70	Cr-N.Stl.	.8400	.134	1.0050	.4020	2.2470
Impeller	.23	Alum.	.1610	.016	.1200	.0480	.3290
Shaft	1.41	Cr-N.Stl.	1.1280	.067	.5025	.2010	1.8315
Balancing	-	-	-	.134	1.0050	.4020	1.4070
Bearings	.30	52100	.3900	.067	.5025	.2010	1.0935
Impeller Hsg.	3.00	Alum.	2.1000	.050	.3750	.1500	2.625
Impeller Hsg. Gv.	.25	Alum.	.1750	.0010	.0075	.0003	.1828
Oil I/O Hsg.	1.00	CI	.4000	.0330	.2475	.0990	.7465
Turbine Hsg.	8.61	CI	3.4440	.083	.6225	.2490	4.3155
			8.638		4.890	1.953	15.481
Wastegate Vlv.	1.00	Steel	.2000	.0670	.5025	.2010	.9035
Wastegate Brkt.	.10	Steel	.0200	.00080	.0060	.0002	.0262
Wastegate Linkage	.15	Steel	.0300	.00080	.0060	.0002	.0362
Hardware	.25	Steel	.0500	.00010	.0075	.0003	.0578
Hose & Fitting	.20	RubStl.	.0400	.0010	.0075	.0003	.0478
			.340		.530	.202	1.072
Total			8.978		5.420	2.155	16.553

Summary	Manufacturing Costs	$16.55
Tooling		1.79
OH & Prod.		9.93
OEM Costs		$28.27 at $1,000,000/Year

TO3 TURBOCHARGER
TOOLING

	Economy of Scale	Recurring Tooling 1 Yr.	Nonrecurring Tooling 3 Yrs.	Equipment 12 Yr.	Launching 12 Yr.	Land & Buildings 40 Yr.	Amortize Per Piece
Turbocharger	1,000,000	36.0	360.0	1,800.0	180.0	10,000	
Turbine Wheel		24.0	240.0	1,200.0	120.0		
Impeller		16.8	168.0	840.0	84.0		
Shaft		12.0	120.0	600.0	60.0		
Balancing		9.6	96.0	480.0	48.0		
Bearings		4.8	48.0	240.0	24.0		
Impeller Hsg.		7.2	72.0	360.0	36.0		
Impeller Hsg. Cov.		.7	7.2	36.0	3.6		
Oil I/O Hsg.		3.6	36.0	180.0	18.0		
Turbine Hsg.		24.0	240.0	1,200.0	120.0		
Wastegate Vlv.		7.2	72.0	360.0	36.0		
Wastegate Brkt.		3.6	36.0	120.0	12.0		
Wastegate Linkage		.7	7.2	36.0	3.6		
Hardware		.7	7.2	36.0	3.6		
Hose & Fitting		1.4	14.4	72.0	7.2		
Totals		151.5	1,524.0	7,560.0	756.0	10,000	
Cost Per Unit		.152	.508	.630	.063	.250	1.603

TO3 TURBOCHARGER
VENDOR COST

Part	Matl	Labor	Plant O.H.	Plant Mfg. Cost	Tooling Exp	Tooling Inv	.20 MC Corp	.20 Corp Pft	Vendor Cost
Turbocharger	8.64	4.89	1.95	15.48	.60	.89	3.10	3.10	23.17
Waste Gate Valve	.34	.53	.20	1.07	.06	.05	.21	.21	1.60
TOTAL	8.98	5.42	2.15	16.55	.66	.94	3.31	3.31	24.77

RETAIL PRICE EQUIVALENT

	Vendor Cost	R&D	Tools & Equip	.20 Corp Alloc	.20 Corp Profit	.40 Dealer M/U	RPE
Turbocharger	23.17	1.00		4.63	4.63	9.26	42.69
Waste Gate	1.60			.32	.32	.64	2.88
Vehicle Assy			.25	.05	.05	.10	.45
Engine Mod.			.25	.05	.05	.10	.45
TOTAL RETAIL PRICE EQUIPMENT							46.47

TURBOCHARGERS - VARIOUS SIZES

The detailed cost estimate for the TO3 Turbocharger has been shown on the preceeding pages. To arrive at estimates for larger sizes, these principles were followed:

- Same economy of scale as the TO3 (1,000,000).
- Material costs increased by weight.
- Labor and overhead increased at 60% the rate material was increased.
- Tools, equipment, launching, land, and building unit costs unchanged.
- Horsepower ratings read from chart at the 55-inch intake manifold pressure level.

TURBOCHARGERS

Engine HP	100	220	250	350	450
Turbocharger Model	TO3 TO4B	TV61	TV71	TV81	T18A
Weight (lbs)	16	36	39	42	43
Material	8.98	20.21	21.89	23.57	24.13
Labor and Overhead	7.57	13.25	14.10	14.95	15.23
Plant Manufacturing Cost	16.55	33.46	35.99	38.52	39.36
Tools, Equipment, Bldgs	1.60	1.60	1.60	1.60	1.60
Corp. O.H. & Profit	6.62	13.38	14.40	15.41	15.74
Vendor Cost	24.77	48.44	51.99	55.53	56.70
R&D	1.00	1.00	1.00	1.00	1.00
Vehicle Assy Tooling	.50	.50	.50	.50	.50
Corp. Alloc. & Profit	10.10	19.38	20.80	22.21	22.68
Dealer M/U	10.10	19.38	20.80	22.21	22.68
Retail Price Equivalent	46.47	88.70	95.09	101.45	103.56

II B - UNIVERSAL FUEL INJECTION SYSTEM

HEAVY DUTY DIESEL ENGINES

The manufacturing and tooling costs estimates on the following pages have been taken from a previous report submitted to D.O.T. They were based on passenger car quantities. The retail price equivalents for truck quantities (50,000/yr.) are given below.

	Automobile Unit Costs			
	4-Cyl	6-Cyl	8-Cyl	EOS Factor
Material	18.88	24.36	29.96	1.3
Labor and Overhead	3.75	4.83	6.16	2.7
Equipment	2.11	2.11	2.11	2.4
Tooling	4.26	4.26	4.26	3.4
Weighted EOS Factors	1.9	1.8	1.8	
X Automobile R.P.E.	70.00	86.54	103.83	
= Truck R.P.E.	133.00	155.77	186.89	

UNIVERSAL FUEL INJECTION SYSTEM

MANUFACTURING COST

	Material	Labor	Plant Over-head	Mfg. Cost
Fuel Filter (Bosch)	.35	.05	.02	.42
Low Pres. Fuel Pump	1.75	.25	.10	2.10
Fuel Piping	2.10	.30	.12	2.52
HP Nozzles - 4 Cyl	4.88	.68	.27	5.83
" " - 6 Cyl	7.32	1.02	.40	8.74
" " - 8 Cyl	9.76	1.36	.54	11.66
Hi Pres. Fuel Pump - 4 Cyl	9.80	1.40	.56	11.76
" " " " - 6 Cyl	12.84	1.84	.73	15.41
" " " " - 8 Cyl	16.00	2.40	.96	19.36
Totals - 4 Cyl	18.88	2.68	1.07	22.63
" - 6 Cyl	24.36	3.46	1.37	29.19
" - 8 Cyl	29.96	4.36	1.74	36.06

UNIVERSAL FUEL INJECTION SYSTEM TOOLING AMORTIZATION

Part	EOS	Recurring Tooling (1 Yr)	Non recurring Tooling (3 Yr)	Machinery Equip. (12 Yr)	Launch Cost (12 Yr)	Land and Building (40 Yr)	Amort per System
Fuel Filter	1,400,000	150	350	1000	200	2000	.30
Low Pres Pump	500,000	50	250	600	100	2000	.50
Fuel Piping	500,000	20	50	130	20	300	.11
Hi Pressure Nozzles	500,000	250	650	1600	300	3000	1.40
Hi Pressure Pump	500,000	750	1950	4800	1000	6000	4.06
Total/System		2.25	2.02	1.25	.25	.60	6.37

UNIVERSAL FUEL INJECTION SYSTEM

MFG/VENDOR COST

		Mfg	Tooling		Corp	Corp	Mfg/Vendor
		Cost	Exp	Inv	Cost	Profit	Cost
Fuel Filter		.42	.19	.11	.08	.08	.88
Low Pressure Pump		2.10	.27	.23	.42	.42	3.44
Fuel Piping		2.52	.07	.04	.51	.51	3.65
Hi Pressure Nozzles	- 4 Cyl	5.83	.93	.47	1.17	1.17	9.57
" " "	- 6 Cyl	8.74	.93	.47	1.75	1.75	13.64
" " "	- 8 Cyl	11.66	.93	.47	2.33	2.33	17.72
Hi Pressure Pump	- 4 Cyl	11.76	2.80	1.26	2.35	2.35	20.52
" " "	- 6 Cyl	15.41	2.80	1.26	3.08	3.08	25.63
" " "	- 8 Cyl	19.36	2.80	1.26	3.87	3.87	31.16
Totals	- 4 Cyl	22.63	4.26	2.11	4.53	4.53	38.06
"	- 6 Cyl	29.19	4.26	2.11	5.84	5.84	47.24
"	- 8 Cyl	36.06	4.26	2.11	7.21	7.21	56.85

UNIVERSAL FUEL INJECTION SYSTEM

RETAIL PRICE EQUIVALENT

	Mfg/ Vendor Cost	R & D	Corp Alloc	Corp Profit	Dealer Mark-Up	Retail Price Equivalent
4 Cyl System	38.06	1.50	7.61	7.61	15.22	70.00
6 Cyl System	47.24	1.50	9.45	9.45	18.90	86.54
8 Cyl System	56.85	1.50	11.37	11.37	22.74	103.83

IIE - HEAVY DUTY DIESEL ENGINE

POSITIVE CRANKCASE VENTILATION VALVE (PCV)

The detailed descriptions and calculations following this page apply to passenger car parts, reprinted from a previous report EPA - 78 - 002, March, 1978. The costs shown therein have been adjusted by using factors, described later in this report, that reflect differences in size and in manufacturing volume (economy of scale) between automobiles and trucks. The EOS used for automobiles is 350,000 per year; for trucks, 50,000.

The resulting retail price equivalent costs for trucks are shown below.

		Automobile Unit Cost	EOS Factor
	Material	$.088	1.3
	Labor and Overhead	.175	2.7
	Equipment	.096	2.4
	Tooling	.036	3.4
	Weighted EOS Factor		2.4
X	Automobile Retail Price Equivalent		$1.14
=	Truck Retail Price Equivalent		$2.74

COST ESTIMATES

PCV Valve System

All engines produce small amounts of blowby gases, which seep past the piston rings, and into the crankcase. These blowby gases are the result of the high pressures developed within the combustion chamber, during the combustion process, and contain undesirable pollutants. To prevent blowby gases from entering the atmosphere, while allowing proper crankcase ventilation, all engines use a PCV system.

The PCV system prevents blowby gases from escaping by routing them through a vacuum controlled ventilating valve, and a hose, into the intake manifold. The blowby gases mix with the air/fuel mixture and are burned in the combustion chambers. When the engine is running, fresh air is drawn into the crankcase through a tube or hose connected to the air cleaner housing.

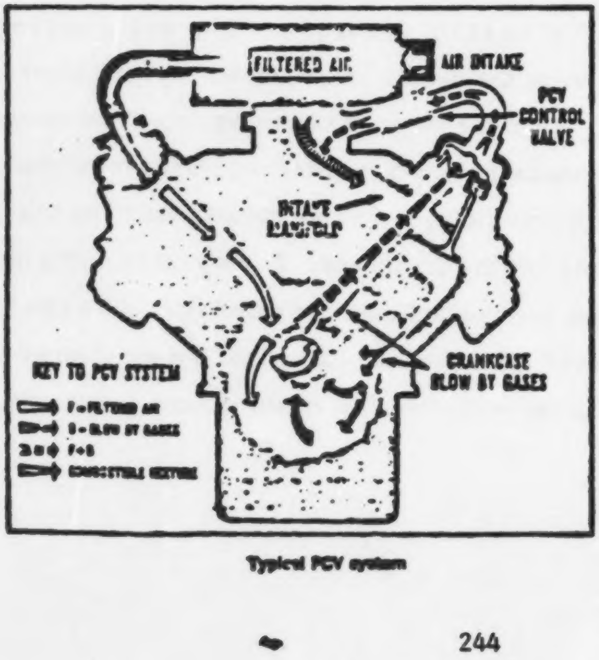
The PCV valve consists of a needle valve, soring and housing. When the engine is off, the spring holds the needle valve closed to stop vapors from entering the intake manifold. When the engine is running, manifold vacuum unseats the valve allowing crankcase vapors to enter the intake manifold. In case of a backfire (in the intake manifold) the valve closes, stopping the backflow and preventing ignition of fumes in the crankcase. During certain engine conditions, more blowby gases are created than the ventilator valve can handle. The excess is returned, through the air intake tube, into the air cleaner and carburetor, where it is disbursed in the air/fuel mixture, and, combusted within the engine.

PCV Valve System

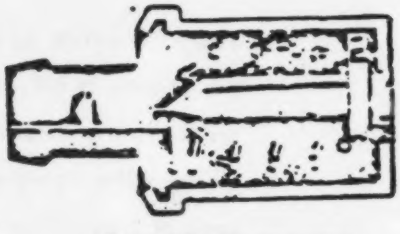
BILL OF MATERIAL

Description	Material	Weight	Mat Costs	Labor Overhead	Mfg Costs	Reference*
PCV Valve		.074	-	.042	.042	6487935
Housing	Steel	.054	.011	.056	.067	
Spring	Spring Steel	.01	.002	.014	.016	
Needle	Steel	.014	.003	.028	.031	
			.016	.140	.156	
Pipe	Steel	.200	.060	.020	.080	8413449
Grommets	Rubber	.020	.004	.005	.009	3989344
Grommets (VC to AC)	Rubber	.040	.008	.010	.018	8412325
Total Parts					.107	
Vehicle Assembly		-	-	.126	.126	
Valve		-	-	.063		
Pipe		-	-	.063		
Engine Modification	-0-	-0-	-0-	.014	.014	
Total Manufacturing Costs at Plant Level					.403	

*Oldsmobile Reference Numbers


FILTERED AIR
AIR INTAKE
PCV CONTROL VALVE
INTAKE MANIFOLD
CRANKCASE BLOW BY GASES
KEY TO PCV SYSTEM
F=FILTERED AIR
B=BLOW BY GASES
F+B
COMBUSTIBLE MIXTURE

Typical PCV system



Typical PCV valve crosssection

PCV Valve System--Tooling Costs--Amortized Per Piece

	Economic Volume Per Year	1 Year Recurring Tooling	3 Year Non-Recurring Tooling	12 Year Machinery Equipment	4 Year Launching Costs	40 Year Land & Buildings	Amortization Per Piece
Valve Assembly							
Housing		.050	.017	.020	.006		.093
Amortized	1,000,000	50,000	50,000	250,000	25,000	-	
Spring		.002	.002	.003	-		.007
Amortized	3,000,000	5,000	15,000	100,000	5,000	-	
Needle		.005	.002	.002	-		.009
Amortized	2,000,000	10,000	12,000	50,000	5,000	-	
		.057	.021	.025	.006 Valve		.109
Pipe		.005	.001	.001	-		.007
Amortized	2,000,000	10,000	5,000	25,000	2,000	-	
Grommets		.004	.002	.002	-		.008
Amortized	4,000,000	15,000	20,000	100,000	5,000	-	
Grommets		.004	.002	.002	-		.008
Amortized	4,000,000	15,000	20,000	100,000	5,000	-	
Total		.013	.005	.005	-		.023
Vehicle Assembly		.001	.001	.0003			.0023
Amortized	300,000	3,000	5,000	10,000	2,000	-	
Engine Modification		.002	.001	.0015	-		.0045
Amortized	300,000	6,000	12,000	60,000	5,000	-	
Total--Tooling/Piece		.003	.002	.0018	-		.1388

Research and Development by Vehicle Manufacturing: $100,000 for 2 Years.

Using a 3-year amortizing rule, the R/D per piece = $.022.

PCV Valve System

TOTAL MANUFACTURING COSTS

Part	Mat	Labor	Plant Over-Head 1.40	Plant Mfg Costs	Tooling		.20 MC Corp Costs	.20 MC Corp Profit	Vendo Corp Sellin Price
					Exp.	Inv.			
PCV Valve	.016	.100	.040	.156	.078	.031	.030	.030	.325
Pipe	.060	.0143	.0057	.080	.006	.001	.016	.016	.119
Grommets	.012	.0107	.004	.0267	.012	.004	.006	.006	.055

PCV Valve System

RETAIL PRICE EQUIVALENT
AT THE VEHICLE LEVEL

Part	Plant or Vendor Selling Price	R&D	Invest Tools & Equip	Corp Allocation .20vc	Corp Profit .20vc	.40sp Dealer Markup	Vehicle Retail Price Equivalent
PCV Valve	.325	.022	-0-	.0652	.0652	.1304	.608
Pipe	.119	-0-	-0-	.0238	.0238	.0576	.224
Grommets	.055	-0-	-0-	.011	.011	.022	.099
Vehicle Assembly	.126	-0-	.0023	.013	.013	.026	.180
Engine Mod	.014	-0-	.0045	.003	.003	.006	.031
Total PCV System Retail Price Equivalent							1.142

PCV Valve System

Cost Comparison to Aftermarket Selling Prices

Using the aftermarket discount data in the references, we can conclude that the vendor selling price is about 1/4 to 1/5 of the aftermarket selling price. This rule is applicable if the part requires a minimum of packaging and handling costs, in relation to the value of the part and if the production volumes are within close agreement.

Using the following aftermarket prices for the PCV valve:

	Chilton	Sears
	3.12	1.76
Vendor Cost 1/4	.78	.44
Vendor Cost 1/5	.62	.35

The estimated vendor cost is $.326 for the PCV valve. This Chilton price is the cost to the customer at the service station.

PCV Valve System
Cost Methodology

The weight data for the components was obtained from an Oldsmobile parts computer document. The material costs are computed by using the 1977 mill prices, obtained from Metalworking News' metals market data. The labor costs are estimates of production, using today's technology, with a relatively high level of automation. The overhead and corporate cost data was obtained from a U.S.A. company.

The tooling costs are estimates of expendable tooling, i.e., jigs, fixtures, molds, or dies; and machinery or equipment, launching costs, to put the product into production at the plant level.

Judgment was used in assessing whether land or building investments were required to put this product into production and it was concluded that they were not.

The engine was modified to accept the valve and the piping, so, these costs are considered as part of the total cost.

The vehicle assembly required the addition of labor to install the valve and the piping.

Applications of PCV Valve systems to vehicle and engine configurations, regarding 4, 6, and 8 cylinder models, was assumed to be equivalent.

IIG - PARTICULATE TRAP - HEAVY DUTY DIESEL ENGINE

Retail Price Equivalents for Various Filter Materials and Volumes

Filter Volume (Cu. In.)

Filter Price Per Lb. (Base)	(Base) 1133	800	1000	1200	1400	1600	1800	2000	2200	2400
$15	$116.89	$89	$103	$119	$134	$149	$164	$179	$194	$209
$ 5	78	50	64	80	95	110	125	140	155	170
$10	97	70	84	100	115	130	145	160	175	190
$20	136	108	122	138	153	168	183	198	213	228
$25	156	128	142	158	173	188	203	218	233	248
$30	175	147	161	177	192	207	222	237	252	267
$35	194	167	181	197	212	227	242	257	272	287

PARTICULATE TRAP - AIR MAZE (HC - 127)

Included are:

a. Pictorial illustration

b. Bill of Materials and Manufacturing Cost Estimates for an 1133 $in.^3$ trap

c. Estimates of other costs and profits to achieve the Vehicle Retail Price Equivalent (same page as b, above)

d. Detail of estimates of investments for tooling and equipment

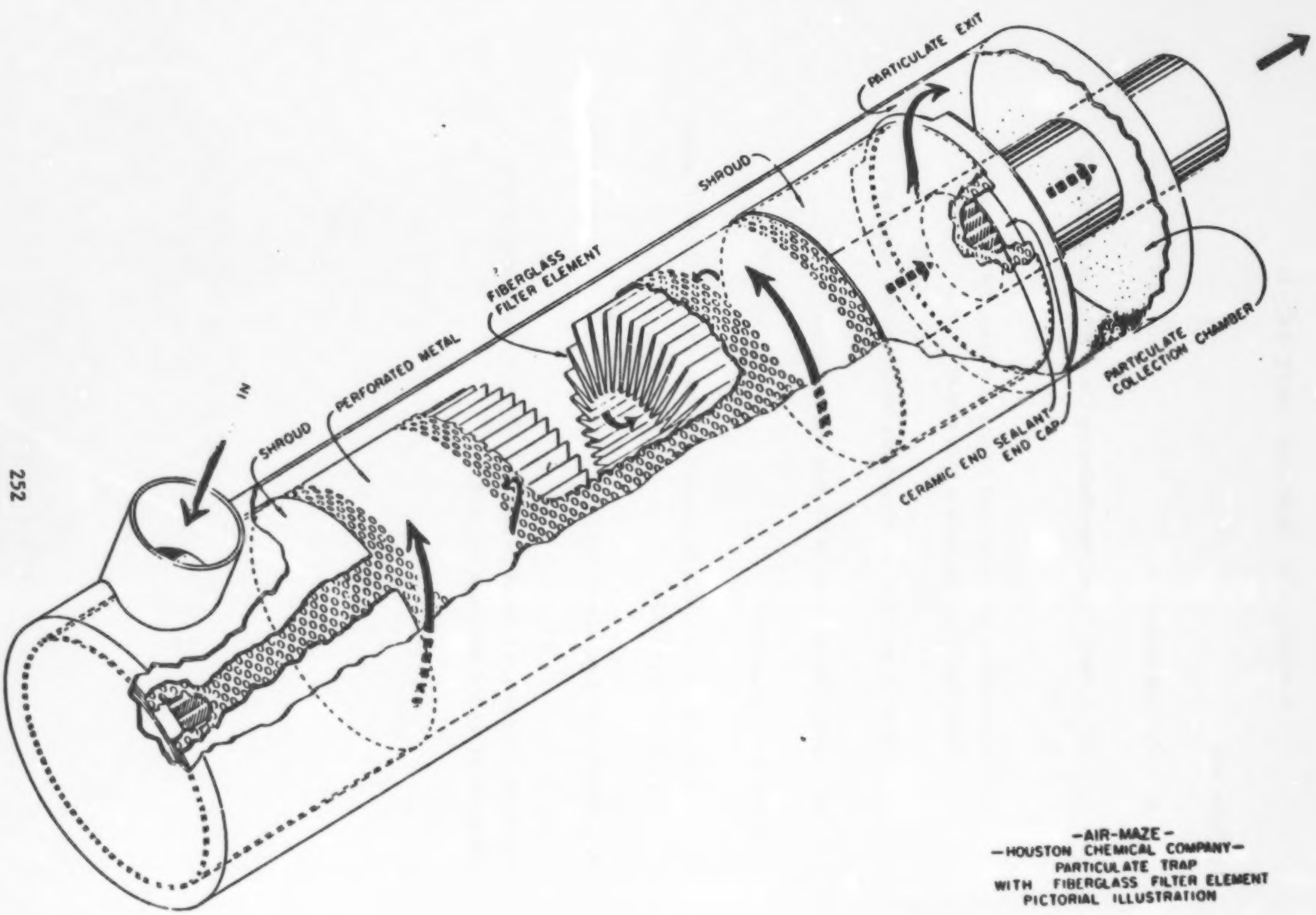
e. Derivation of formulae for size extrapolations

Two formulae are pertinent:

I. Manufacturing Cost (MC) for another size trap = \$5.08 + (33.89) F where F = new volume ÷ 1133

II. Retail Price Equivalent = (2.52) MC + \$15.48

For ready reference, a table of retail price equivalents for a range of sizes and prices of filter materials is presented.


IN
SHROUD
PERFORATED METAL
FIBERGLASS
FILTER ELEMENT
SHROUD
PARTICULATE EXIT
CERAMIC END SEALANT
END CAP
PARTICULATE
COLLECTION CHAMBER

-AIR-MAZE-
—HOUSTON CHEMICAL COMPANY—
PARTICULATE TRAP
WITH FIBERGLASS FILTER ELEMENT
PICTORIAL ILLUSTRATION

4-19-74

HC-127
(HCC-127)

J MC CLELLAND

PARTICULATE TRAPS - AIR MAZE, HC - 127

Derivation Of Formula For Size Variation By Adjusting Length Only

Structural Parts

The basic costed unit has 1133 in.^{3} filter chamber volume. This chamber is cylindrically shaped:

_______ 42" Long x 5.86 Diameter = 1133 in.^{3}

Assume that any increases or decreases in this volume will be made by changing the length of the cylinder (Diameter unchanged)

Then the only structural components changed will be: (a) Outer cylinder and (b) Perforated metal cylinder.

Referring to the Manufacturing Cost Estimate:

Structural Components	Mfg. Cost	Length
Outer Cyl.	$ 9.77	48"
Perf. Metal Cyl.	2.73	42"
Sub Total	$12.50 (=76%)	
Other	3.90	
Total	$16.40	

If we shorten the Perforated Metal Cylinder by Z%, the filter chamber volume is reduced Z%.

Simultaneously, this shortens the Outer Cylinder by 42/48 X Z%, or 0.875 X Z%.

The net effect on Manufacturing Cost of Structural Components caused by a reduction (or an increase) of Z% in filter chamber volume will be:

$$\$\text{ M.C.} = \left[.875\,(\$9.77) + \$2.73\right]\,(Z\%)$$

$$\$\text{ M. C.} = \$11.28\,(Z\%)$$

This amount, related to the M. C. of the 1133 in^3 unit, can be stated as a proportional change in the total M. C.

% change in M. C. of structural components = 11.28/16.40 Z% = .69 Z%

The manufacturing cost of structural components resulting from changing the filter volume by a factor F can therefore be calculated by this equation:

$$\text{Total Mfg. Cost} = 16.40\left[1 + .69\,(F - 1)\right]$$

$$\text{Total Mfg. Cost} = 16.40\,(.31 + .69F)$$

$$\text{Total Mfg. Cost} = 5.08 + 11.32\,F$$

Where F = New volume ÷ 1133

Example:

What is the estimated total manufacturing cost of a particulate trap having an 800 $in.^3$ filter chamber?

Relative change in vol. = 800/1133 = .706 = F

Put F into the structural components equation:

New mfg. cost of structural components = 5.08 + 11.32 (.706) = $13.07

add proportional cost for filter

22.57 x .706 =	15.93
Total Mfg. Cost	$29.00

Derivation

Airmaze Particulate Trap. (HC - 127) Converting Manufacturing Cost (MC) To Vehicle Retail Price Equivalent (RPE)

		Computation
a.	MC of unit	(formula)
b.	+ MC of Vehicle Ass'n. and Body Mod.	$ .36
c.	+ Tooling	6.57
d.	+ O. H.	.20 (a + b)
e.	+ Profit	.20 (a + b)
f.	+ R & D	2.00
g.	+ T & E	.93
h.	+ Corp. Alloc	.20 (a+b+c+d+e)
j.	+ Corp. Profit	.20 (a+b+c+d+e)
k.	+ Dealer M/U	.40 (a+b+c+d+e)
	= RPE	

Combining:

$$RPE = \left[MC + .36 + 6.47 + .4\,(MC + .36)\right](1.8) + 2.93$$

$$RPE = 2.52\ MC + 15.48$$

PARTICULATE TRAP - AIR MAZE HC-127
(1133 cu. in. filter chamber)

COSTS PER UNIT

Part	Mat'l.	Fin. Wgt. (Lbs.)	Mfg. Cost				Tooling			Corporate		Plant/ Vendor Cost	R&D	Tools Equip	Corp. Alloc (.2 Vend Cost)	Corp. Profit (.2 Vend) Cost)	Dealer Mark-Up (.4 Vend Cost)	Vehicle Price Equi- valent
			Matl. *	Labor	O.H.	Tot.	Exp.	Inv.	Tot.	O.H. (.20 Mfg. Cost)	Profit (.20 Mfg. Cost)							
Col.# Deriv'n	1	2	3	4	5	6 (3+4+5)	7	8	9 (7+8)	10	11	12 (6+9+10+11)	13	14	15	16	17	18 (12+(13-17))
Structural Elements																		
Outer Cylinder	SS	17.7	$9.56	$.15	$.06	$9.77												
Outer End (2)	SS	1.2	.65	.03	.01	.69												
Inlet Pipe	SS	0.6	.32	.08	.03	.43												
Outlet Pipe	SS	1.1	.59	.08	.03	.70												
Inlet Shroud	SS	1.3	.70	.08	.03	.81												
Outlet Shroud Cyl.	SS	1.3	.70	.08	.03	.81												
Outlet Shroud Cap Bot	SS	0.3	.16	.03	.01	.20												
Outlet Shroud Cap Shoulder	SS	0.2	.11	.03	.01	.15												
Perf. Metal Cyl.	SS	2.2	2.38	.25	.10	2.73												
End Sealant	Ceramic	0.2	.10	.01	-	.11												
Components		25.9	15.27	.82	.31	16.40	3.36	.44	3.80	[illegible]	3.28	26.76	2.00		5.35	5.35	10.70	50.16
Assembly			-	.80	.32	1.12	.60	.19	.79	.23	.23	2.37			.47	.47	.92	4.23
Filter - Accordion	F/GLS	1.5	22.50	.05	.02	22.57	.60	.18	.78	4.51	4.51	32.37			6.47	6.47	12.95	58.26
TOTAL		27.4	37.77	1.67	.65	40.09	4.56	.81	5.37	8.02	8.02	61.50	2.00		12.29	12.29	24.57	112.65
Vehicle Assembly				.13	.05	.18	.60	.23	.83	.04	.04	1.09		.85	.22	.22	.44	2.82
Body Modification			--	.13	.05	.18	.33	.04	.37	.04	.04	.63		.08	.13	.13	.25	1.22
GRAND TOTAL			37.77	1.93	.75	40.45	5.49	1.08	6.57	8.10	8.10	63.22	2.00	.93	12.64	12.64	25.26	116.69

AIR - MAZE PARTICULATE TRAP HC - 127 - TOOLING COST AMORTIZATION PER PIECE

(1133 cu. in. filter chamber)

(Volume And $ Expressed in 100's)	Yearly Volume	1 Year Recurring Tooling	3 Year Non-Recurring Tooling	12 Year Machinery And Equipment	12 Year Launching Cost	40 Year Land and Building	Amortization Per Piece
Structural Elements							
Outer Cylinder	50	.30 15	.30 45	.08 50	.07 5		.69 115
Outer Cyl. End (2)	100	.05 5	.03 10	.01 10	- 1		.09 26
Inlet Pipe	50	.10 5	.10 15	.03 15	.01 1		.24 36
Outlet Pipe	50	.10 5	.10 15	.03 15	- 1		.23 36
Inlet Shroud Cyl.	50	.20 10	.17 25	.04 25	.01 2		.42 62
Outlet Shroud Cyl.	50	.20 10	.17 25	.04 25	- 2		.41 62
Outlet Cap - Body	50	.10 5	.07 10	.02 10	.01 1		.20 26
Outlet Cap-Shoulder	50	.10 5	.07 10	.02 10	- 1		.19 26
Perf. Metal Cyl.	50	.30 15	.30 45	.08 50	.01 5		.69 115
End Sealant	50	.30 15	.30 45	.03 15	.01 5		.64 80
Assembly	50	.30 15	.30 45	.08 50	.01 5	.10 200	.79 315
SUB TOTAL		2.05 105	1.91 290	.46 275	.07 29	.10 200	4.59 1899
Filter Elements							
Accordion Tube	50	.30 15	.30 45	.17 100	.01 5		.78 165
SUB TOTAL		.30 15	.30 45	.17 100	.01 5	-	.78 165
Vehicle Assembly	50	.30 15	.30 45	.21 125	.02 15		.83 200
Body Modification	50	.30 15	.03 5	.03 15	.01 2		.37 37
GRAND TOTAL		2.95 150	2.54 385	.87 515	.11 51	.10 200	6.57 1301

APPENDIX

METHODOLOGY
COST DERIVATION

DEVELOPMENT OF USEFULLY ACCURATE METHODOLOGIES FOR ESTIMATING MANUFACTURING COSTS OF AUTOMOTIVE COMPONENTS

General Discussion

It must be recognized as a reality that the manufacturing cost of a component can never be pinpointed.

Vendor qualifications (quality, delivery performance, second-source considerations) contribute to variation in the cost of the component. Internal operations also contribute to the variation (method changes, scrap rates, tolerance adjustments).

The point being made is that any estimate of a component's cost is subject to some error.

The question then becomes, "How big an error is allowable?" ("Can it be accepted?")

COST VERSUS WEIGHT METHODOLOGY

Logic dictates that, all things being equal, the manufacturing costs of parts of a given material should bear some rational relationship to their weights: there is more material in the heavier piece; its very weight or size should tend to slow down the rate at which it can be processed.

Of course all things are not equal. One piece is more complex than another, requiring additional operations, thereby pushing up its cost. And this means that although, in aggregate, a good correlation between weight and cost does exist, the estimated cost of a single item based on its weight alone is subject to a measurable degree of probable inaccuracy.

To clarify a bit the laws of inaccuracy (generally called laws of probability) consider the following synthetic example:

Suppose a formula says that 95% of the one-pound pieces cost $1.00 plus or minus $.20.

1. This means that were you to select one piece, weigh it, find that it weighed one pound and so cost it at $1.00, you could be incorrect by $.20.

2. The very same formula inherently implies that were 25 different one-pound pieces priced, the total would be in error by only plus or minus $1.00, since some would err on the high side and others on the low.

3. The average per-piece error decreases by the square root of the number of pieces averaged.

WEIGHT-COST CORRELATION FORMULAE

The Manufacturing Costs used in the data base are, for the most part, derived from mathematical equations that relate the weight of a piece to its Manufacturing Cost. The equations are all linear and of the familiar slope-and-intercept form $y = ax + b$.

The equations, the development of which is described in subsequent text, are given in Exhibit 1.

Exhibit 1

FORMULAE FOR ESTIMATING THE MANUFACTURING COST OF A PART WHEN ITS WEIGHT IS KNOWN

Material	Formula Modifiers		Wgt Lbs	x	$ Cost Equals Slope Factor (a)	+	Intercept (b)
Stamped Steel	Simple Parts:	up to 4 lbs.*	(W	x	$ .233)	+	$.030
Stamped Steel	Medium Parts:	up to 4 lbs.*	(W	x	.30)	+	.080
Stamped Steel	Complex:	up to 4 lbs.*	(W	x	.367)	+	.13
Steel Wire			(W	x	.439)	+	.034
Aluminum			(W	x	.238)	+	.461
Plastic	Light:	up to 0.1 lbs.	(W	x	2.03)	+	.013
Plastic	Heavy:	over 0.1 lbs.	(W	x	.438)	+	.102
Die Cast Zinc			(W	x	1.19)	+	.144
Rubber			(W	x	1.109)	+	.014

*Beyond this limit, engineering estimates should be made.

DEVELOPMENT OF THE WEIGHT-COST CORRELATION FORMULAE

Data Sources

Three separate sets of cost estimations, each from a different source, were used in arriving at the equations presented. On all three, the cost of a part was established by the universally-used industrial engineering technique: an experienced machine tool engineer, having a wide background knowledge of processing methods and rates and having information on the dimensions and configuration of a given piece, can predict its cost within close limits.

The three sources:

A. Pioneer Engineering and Manufacturing Corporation report, February 1976; Report No. DOT-HS-5-01081.

B. Budd Minicar study (DOT/HTSA).

C. Rath & Strong report (DOT/TSC 1067).

Computation Procedures - General

Each set of data was analyzed separately. The three analyses were compared and found to be in good agreement, with some isolated instances of parts not fitting the overall weight-cost correlation pattern. These relatively few significant deviations were individually examined and virtually all were rationally explained. (Main causes were (1) erroneous classification of assemblies as parts and (2) heavier steel parts, over 5 pounds, do not exhibit a close enough relationship between weight and cost.)

The three analyses were then amalgamated into one best solution, resulting in the formulae presented previously in Exhibit 1.

COMPUTATION PROCEDURE - SPECIFIC EXAMPLES

Example 1 - Stamped Steel - Pioneer Data

(As described in the referenced Pioneer report, a 1975 Chevelle Coupe was completely dismantled and a detailed analysis made of each component; weights were recorded and manufacturing costs were estimated, using "procedures and techniques adapted from the automotive industry;" with 350,000 units per year and September 1, 1975 labor rates and material cost as a base.)

The weight and cost figures given were first graphed into a scatter plot.

Visual analysis of the plotted points indicated that while a weight-cost correlation clearly existed, the points were not normally distributed about any "best-fit" central line. In other words, two families of parts existed--a so-called bimodal distribution of "simple" and "complex" parts.

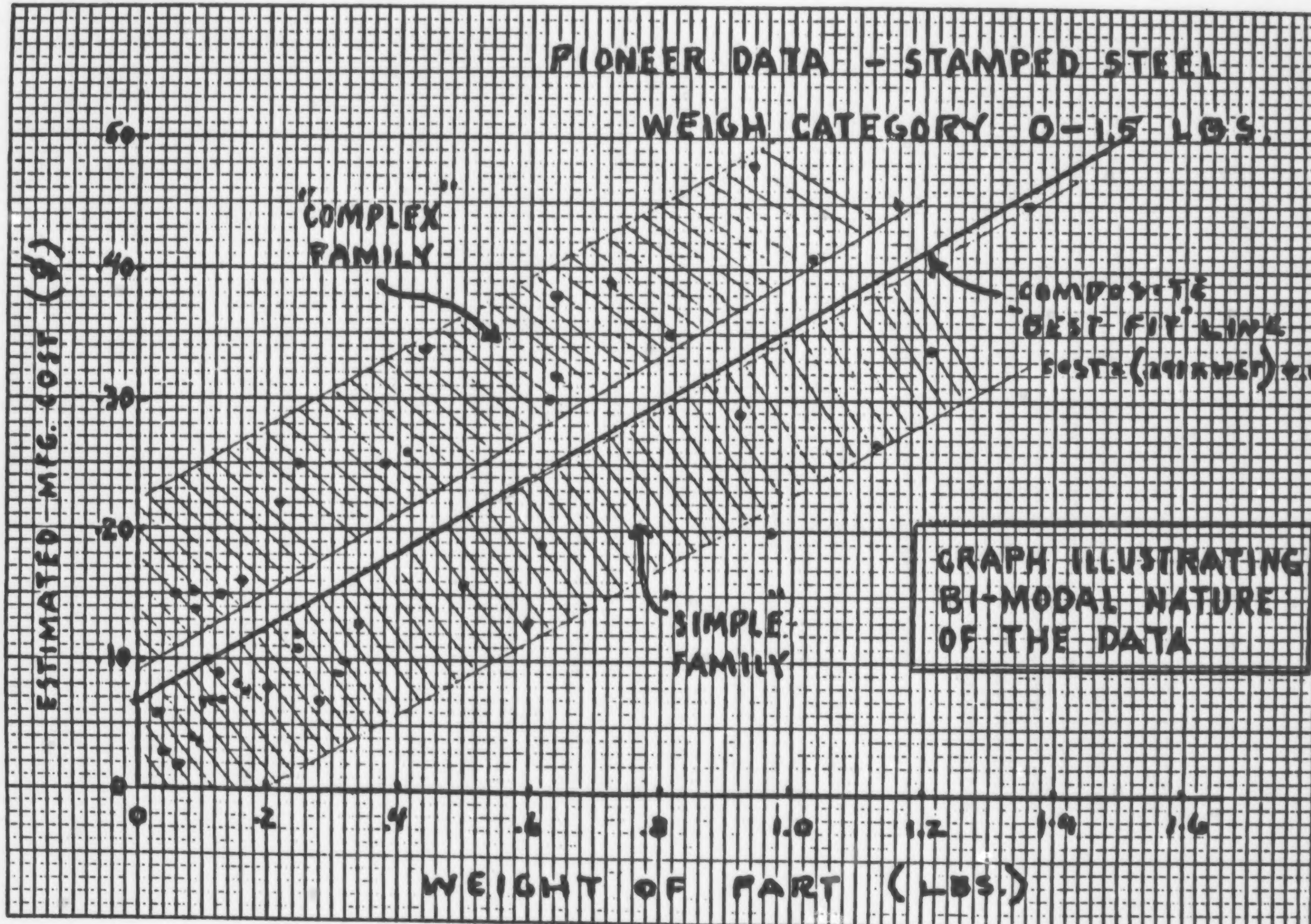
Exhibit 2, which covers the weight range from 0 to 1.5 pounds, most clearly demonstrates this bimodal characteristic. The same distinctness of families pertains up to 4 pounds; beyond this weight the correlation of weight and cost becomes too weak to be useful.

Two linear regression lines are required; one for the "simple" family and one for the "complex," as shown in Exhibit 3.

Exhibit 4 displays the 0-3.99 pounds raw data from the Pioneer report and also the part-by-part comparison with them and the values derived from the best fit lines. As can be seen, 52 parts are involved which, on a one-each basis, are estimated to cost $14.33, against which the weight-cost correlation equations give an estimate of $14.60; a difference in total of only $.27 and the largest single part error is $.13.

NO. 325. 10 DIVISIONS PER INCH BOTH WAYS. 70 BY 100 DIVISIONS. Codex GRAPH PAPER

Exhibit 2



PIONEER DATA - STAMPED STEEL

WEIGH CATEGORY 0-1.5 LBS.

"COMPLEX" FAMILY

"SIMPLE" FAMILY

COMPOSITE BEST FIT LINE

COST=(29.1xWGT)+7.066

GRAPH ILLUSTRATING BI-MODAL NATURE OF THE DATA

1/6/77

Exhibit 4

STAMPED STEEL--COMPARISON OF PIONEER ESTIMATES AND WEIGHT-COST EQUATIONS VALUES (0-3.99 POUNDS)

Pioneer Data (Ranked by Wgt) Lbs.	$	Class* of Part	Weight-Cost Equation $	Diff. (Over)
.03	$.06	S	$.04	$-.02
.04	.03	S	.04	.01
.06	.02	S	.04	.02
.09	.04	S	.05	.01
.09	.04	S	.05	.01
.10	.07	S	.05	-.02
.11	.10	S	.06	-.04
.12	.07	S	.06	-.01
.13	.07	S	.06	-.01
.13	.09	S	.06	-.03
.16	.08	S	.07	-.01
.16	.08	S	.07	-.01
.20	.08	S	.08	-
.25	.12	S	.09	-.03
.25	.11	S	.09	-.02
.28	.07	S	.10	.03
.31	.09	S	.10	.01
.32	.10	S	.10	-
.34	.13	S	.11	-.02
.50	.16	S	.15	-.01
.60	.13	S	.17	.04
.62	.19	S	.17	-.02
.94	.29	S	.25	-.04
.97	.20	S	.26	.06
1.13	.27	S	.29	.02
1.21	.34	S	.31	-.03
1.88	.45	S	.47	.02
1.97	.55	S	.49	-.06
2.16	.46	S	.53	.07
2.38	.64	S	.58	-.06
2.81	$ .55	S	$ .68	$ .13
2.81	.55	S	.68	.13
Subtotal				
	$6.23	S	$6.35	$ .12
.06	.15	C	.15	-
.09	.14	C	.16	.02
.09	.15	C	.16	.01
.13	.15	C	.18	.03
.16	.16	C	.19	.03
.22	.22	C	.21	-.01
.25	.25	C	.22	-.03
.38	.25	C	.27	.02
.41	.26	C	.28	.02
.44	.34	C	.29	-.05
.63	.30	C	.36	.06
.64	.38	C	.36	-.02
.64	.32	C	.36	.04
.72	.39	C	.39	-
.81	.35	C	.43	.08
.94	.48	C	.47	-.01
1.75	.91	C	.77	-.14
1.91	.82	C	.83	.01
2.25	.89	C	.96	.07
2.93	1.19	C	1.21	.02
Subtotal				
	$8.10	C	$8.25	$ .15
Grand Total				
	$14.33		$14.60	$ .27

*Simple = S Complex = C

Example 2 - Plastic

The data on plastic parts given in the Pioneer report was analyzed in a manner similar to that described in Example 1.

Here, the scatter-plotted points, Exhibit 5, showed a clear delineation between the lighter (up to 0.1 pounds) and the heavier parts. Two best-fit lines describe closely the relations between weight and estimated cost.

Exhibit 6 presents the raw data and the comparable mathematically-generated values. On a one-each basis, both methods give a total of $3.69 for the 19 pieces involved, and the greatest individual deviation is $.07.

Exhibit 5

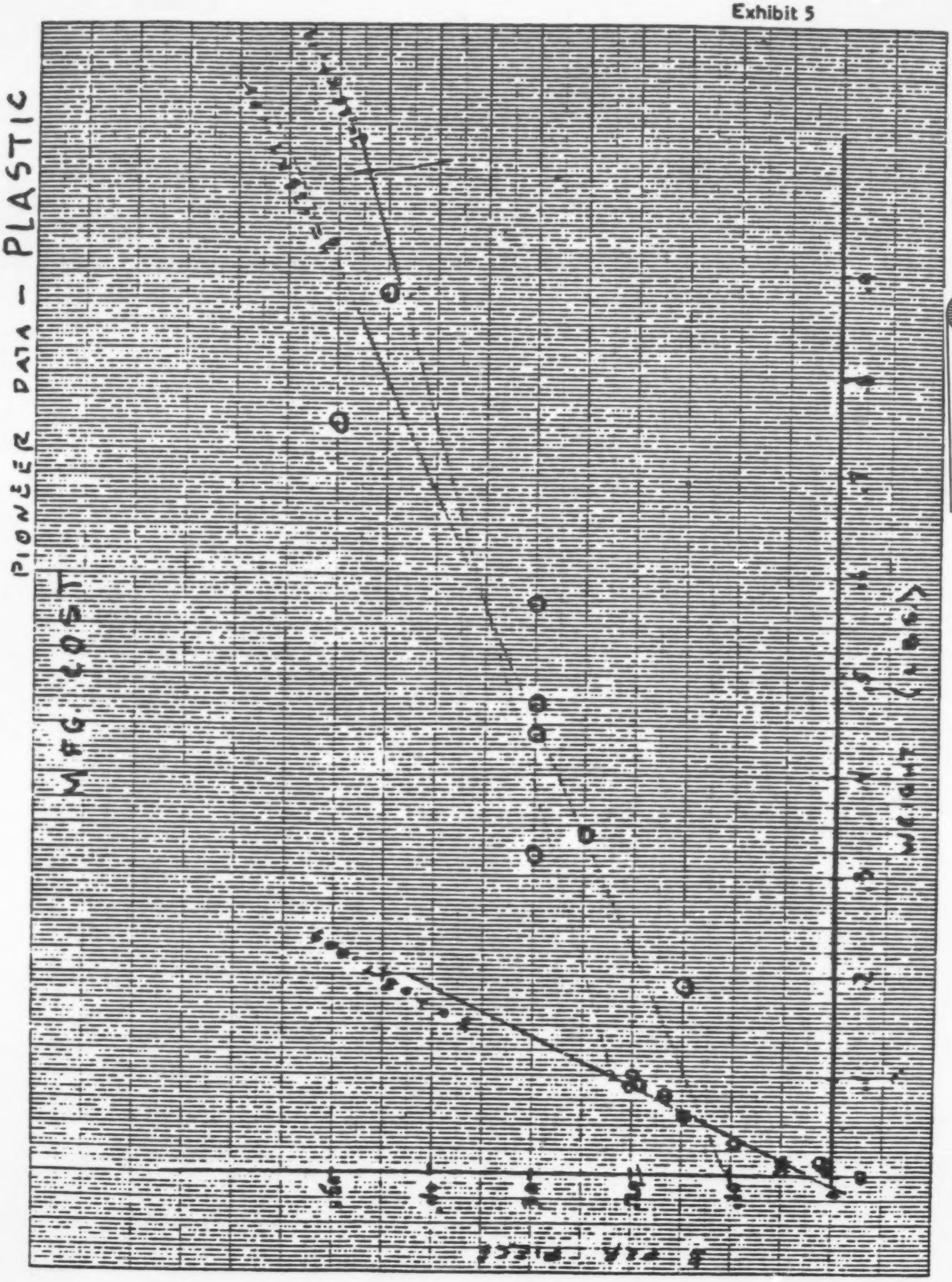


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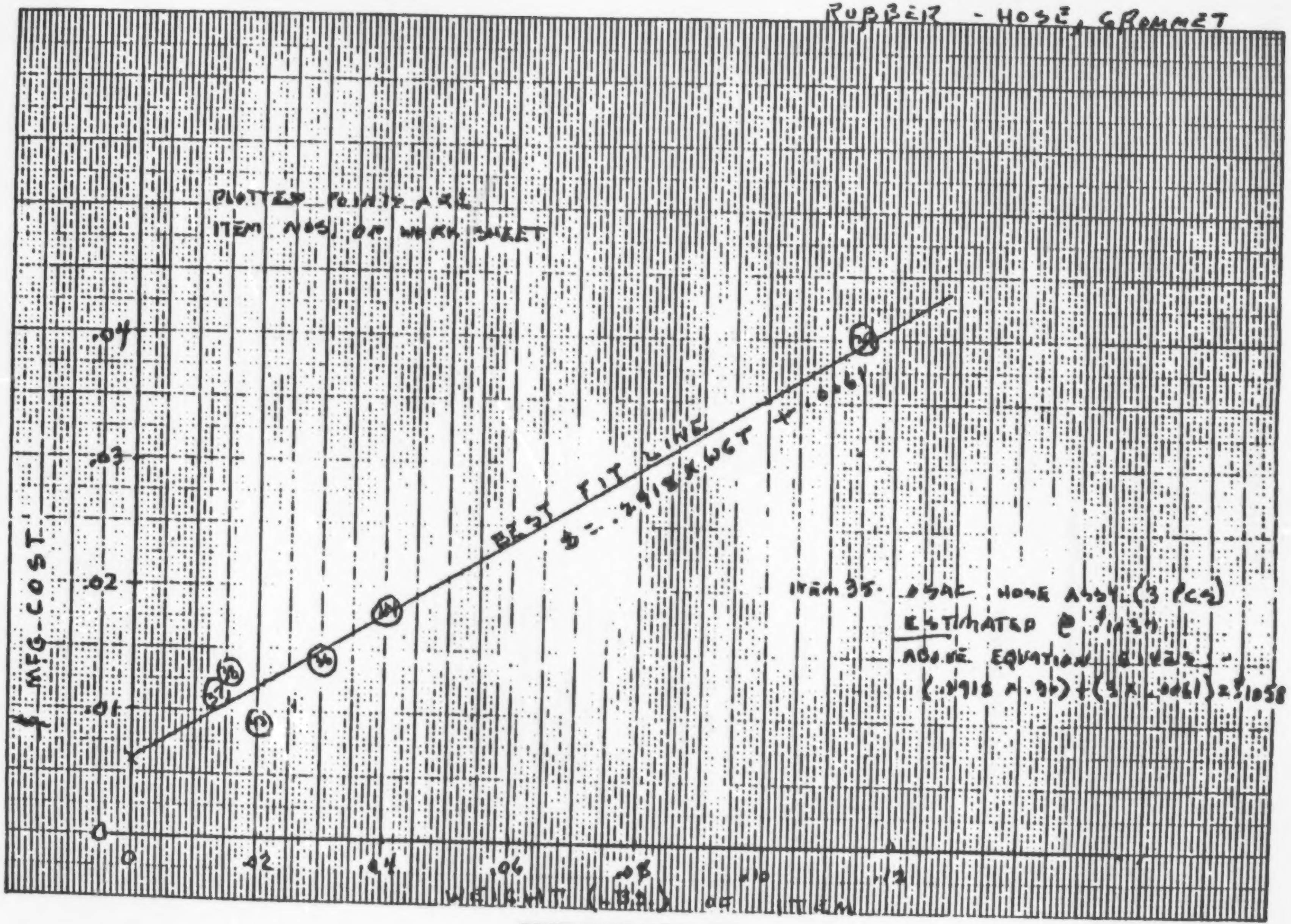
Exhibit 6

PLASTIC--COMPARISON OF PIONEER ESTIMATES AND WEIGHT-COST EQUATIONS VALUES

Pioneer Data			Weight-Cost Equation	
Lbs.	$	Weight Class	$	$ Diff. (Over)
.005	$ .005	Light	$ .02	$ .015
.005	.05	Light	.02	-.03
.01	.005	Light	.03	.025
.01	.01	Light	.03	.02
.01	.05	Light	.03	-.02
.03	.10	Light	.07	-.03
.06	.15	Light	.14	-.01
.08	.17	Light	.18	.01
.09	.20	Light	.20	-
.09	.20	Light	.20	-
.10	.20	Light	.22	.02
		Subtotal		
	$1.14	Light	$1.14	-
.19	.15	Heavy	.19	.04
.32	.30	Heavy	.24	-.06
.34	.25	Heavy	.25	-
.44	.30	Heavy	.29	-.01
.47	.30	Heavy	.31	.01
.57	.30	Heavy	.35	.05
.75	.50	Heavy	.43	-.07
.88	.45	Heavy	.49	.04
		Subtotal		
	$2.55	Heavy	$2.55	-
		Grand Total		
	$3.69		$3.69	-

REFERENCE

RUBBER - HOSE, GROMMET



PLOTTED POINTS ARE
ITEM NOS. ON WORK SHEET

$ = .2918 × WGT + .0061

ITEM 35. DSAE HOSE ASSY. (3 PCS)
ESTIMATED @ $.1434
ABOVE EQUATION GIVES -
(.2918 × .30) + (3 × .0061) = $.1058

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Budd Company Report 0323-1 (DOT-HS-5-01215)

RESEARCH SAFETY VEHICLE PRODUCIBILITY AND COST STUDY FOR MINICARS, INC.--November 5, 1976

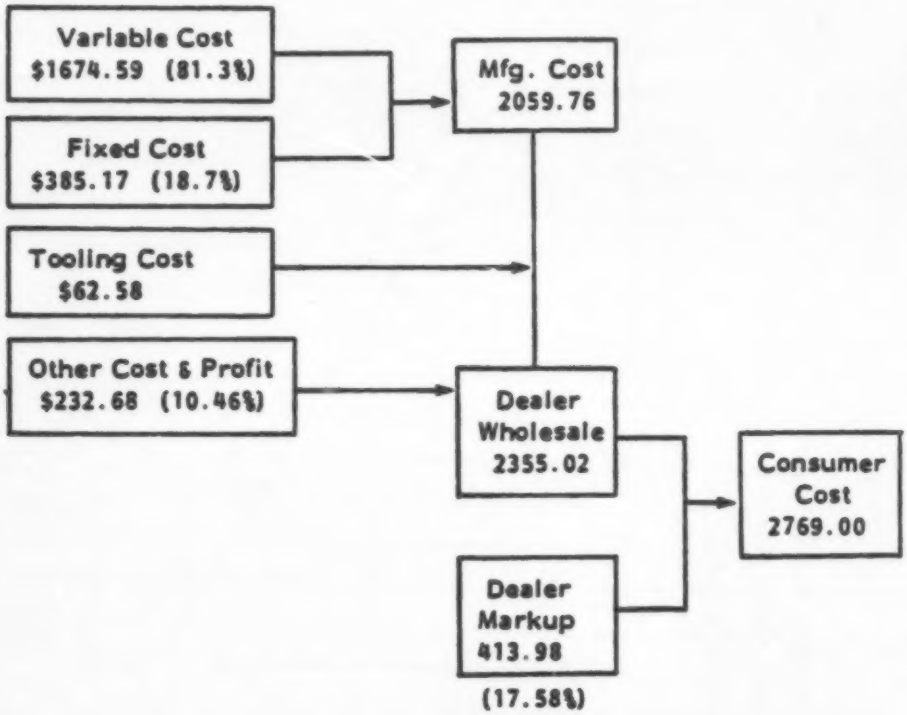
Volume Basis - 300,000 Units/Year

All Costs in 1975 Dollars

Costing Data Developed from 1975 Pinto.

→ <Data Obtained from NHTSA Contract HS-5-00153>

1975 Pinto Cost Data:


Variable Cost
$1674.59 (81.3%)
Fixed Cost
$385.17 (18.7%)
Tooling Cost
$62.58
Other Cost & Profit
$232.68 (10.46%)
Mfg. Cost
2059.76
Dealer Wholesale
2355.02
Dealer Markup
413.98
(17.58%)
Consumer Cost
2769.00

Budd Company (Continued)

Baseline data generated by Pioneer Engineering and Manufacturing Corporation, DOT-HS-5-01153.

Each part of the Minicar reviewed as to number of operations to form it and the tooling costs--then compared to similar Pinto parts and comparative costs established.

In-depth study of Pinto data made to accommodate manufacturing sequence differences between Pinto and Minicar.

FORMULAE FOR BUDD DATA

24 GA. CRS - $/Pc = $.10 + ($.25) WGT

48 GA. CRS - $/Pc = $.20 + ($.29) WGT

FORMULAE FOR PIONEER DATA

STAMPED STEEL

0 - 2# $y = .07 + .32\,x$

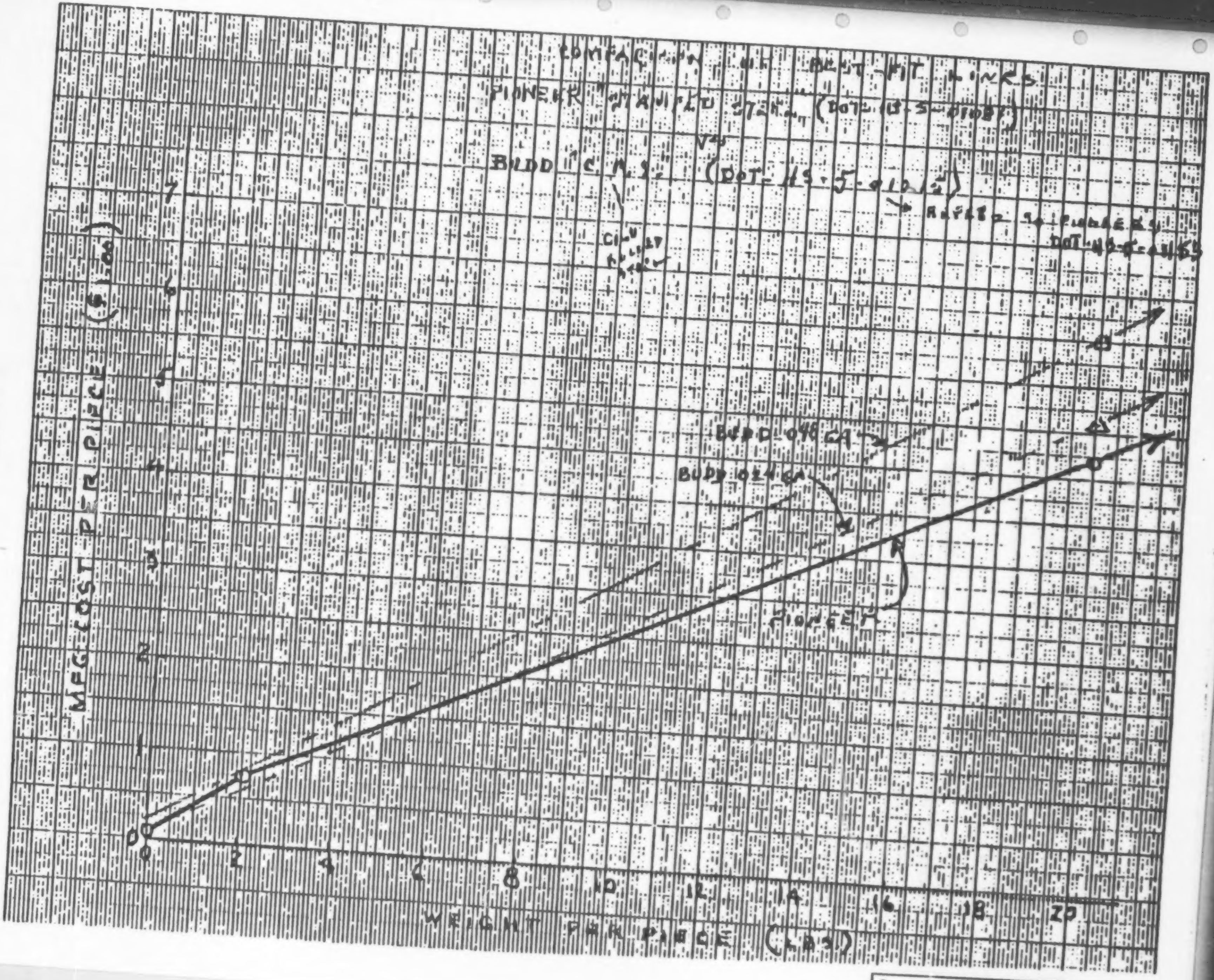
2# - 5# $y = .75 + 0\,x$

5# - 40# $y = .14 + .22\,x$

Final Revision: --

0 - 2# $y = .08 + .33\,x$

2^+#- 40# $y = .30 + .22\,x$



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PIONEER ENGINEERING & MANUFACTURING CORPORATION

February 1976

DOT-HS-5-01081

(Note: This one, based on Intermediate Type Car, is not the same one referred to by Budd, which spoke of a 1975 Pinto.)

1975 Chevelle Coupe

Car dismantled, detailed analysis of components made; weights recorded; manufacturing costs estimated.

"Cost estimating procedures and techniques adapted from the automotive industry."

(Gives bibliography of other studies using same estimating practices.)

Final Assembly Labor = 24 Hours

Volume - 350,000 Units/Year

September 1, 1975 Labor Rates and Materials Costs

Graphical analysis of the "Stamped Steel" data in the Pioneer report DOT-HS-5-01081 leads to these observations and conclusions:

1. A simple linear regression, ("best fit") line relating piece cost and piece weight is not a practical model.

2. The data are not scattered about this central line in a normal distribution pattern. Rather, they form a Bi- or Multi-Modal distribution.

3. This Multi-Modal character of the data is a natural reflection of the various complexities of the pieces (complexity here implies number and types of operations as well as skeleton scrap at blanking and piercing.

4. Three levels of complexity classification are recommended:

   (a) Simple

   $/Pc = $.03 + ($.233 x lbs.)

   (b) Medium

   $/Pc = $.08 + ($.30 x lbs.)

   (c) Complex

   $/Pc = $.13 + ($.367 x lbs.)

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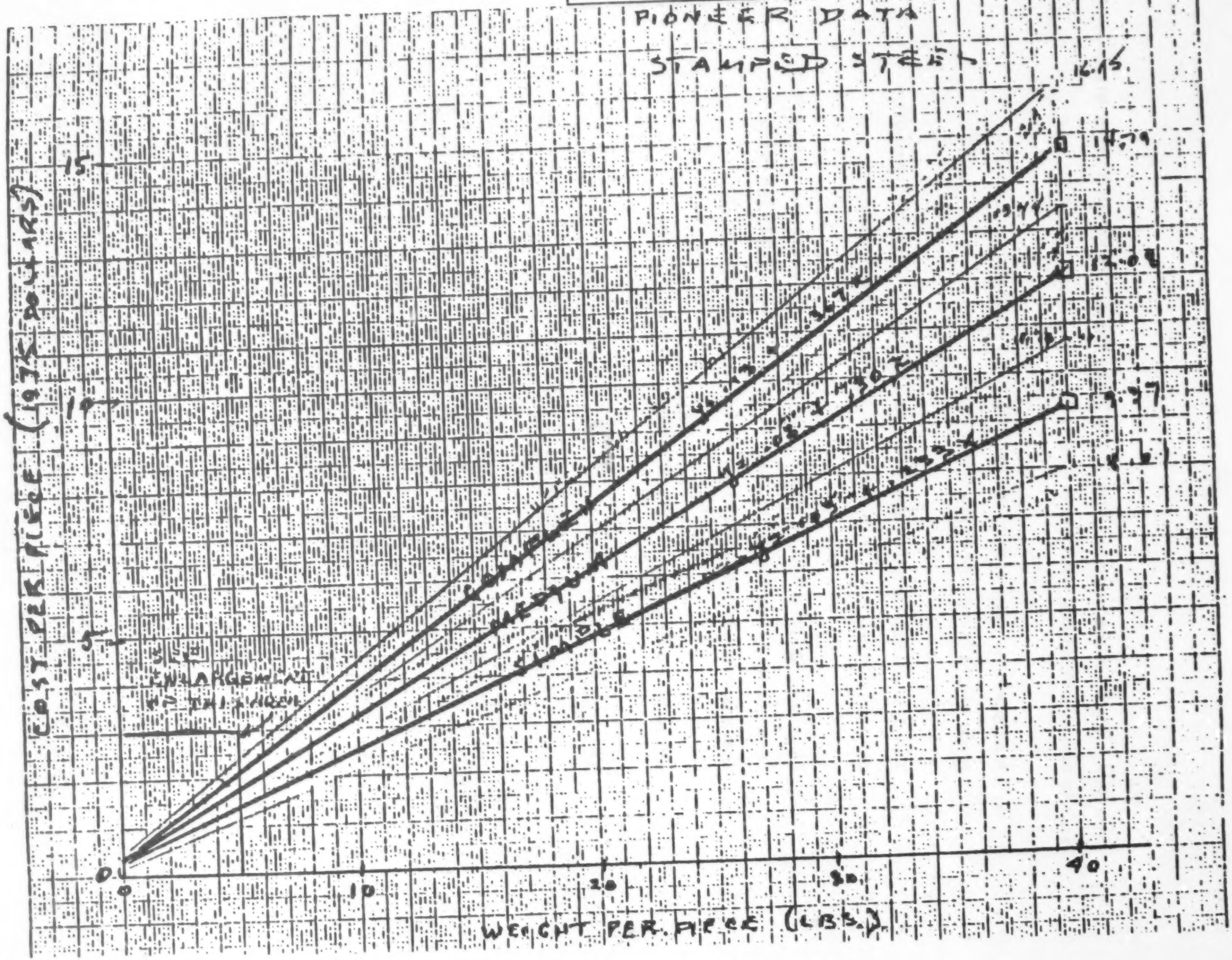
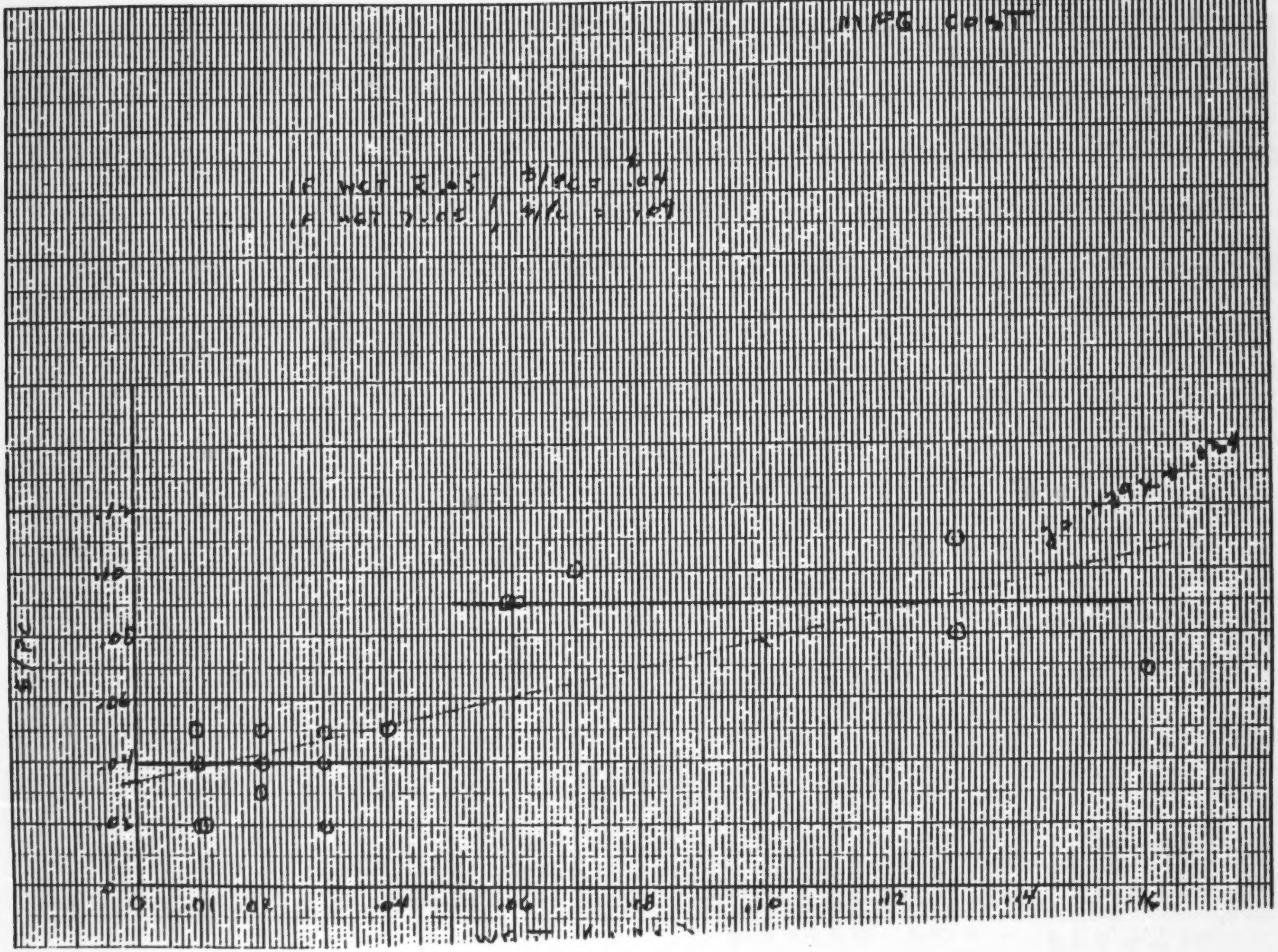
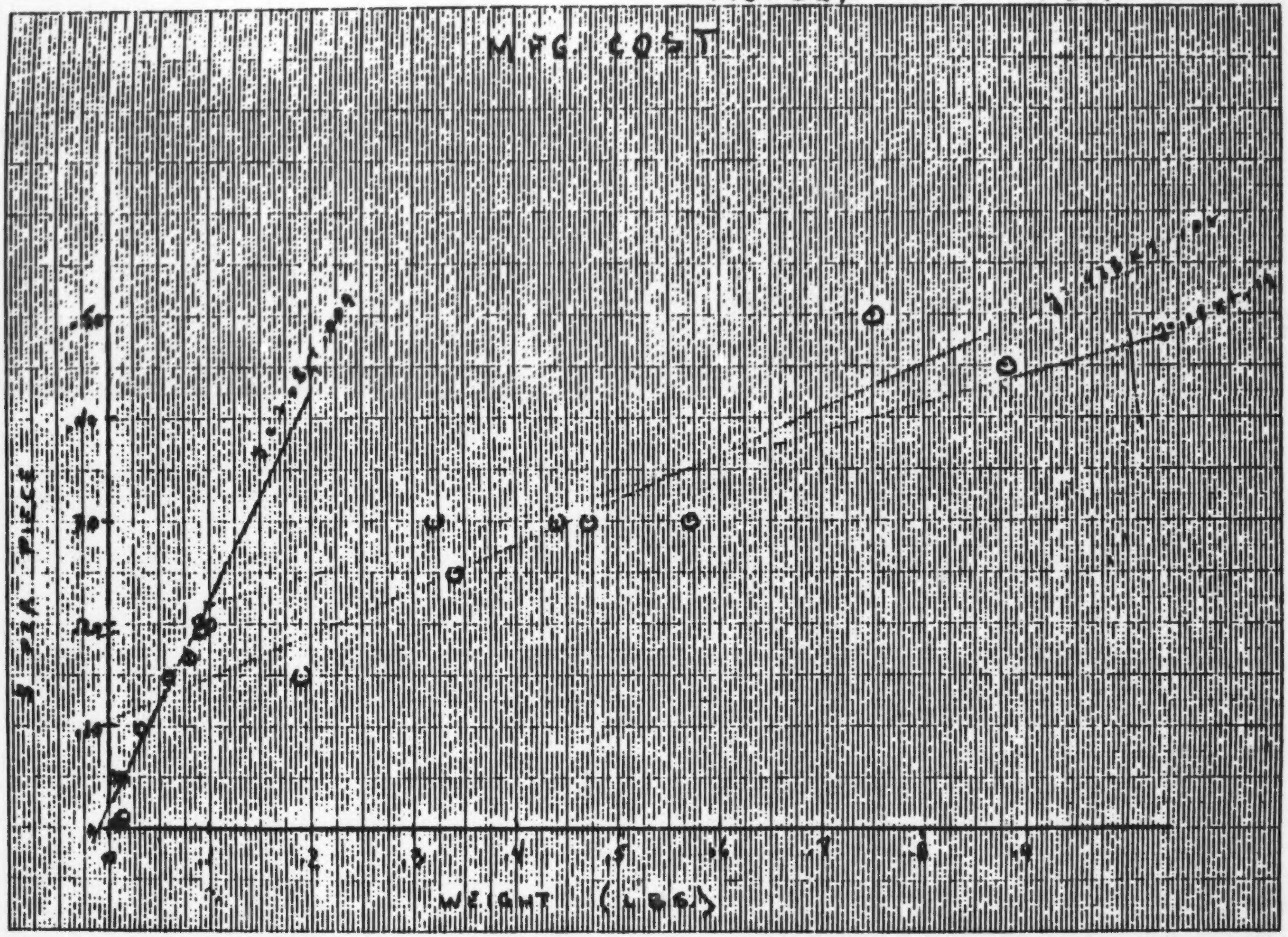


PIONEER DATA — STEEL WIRE
MHG COAT

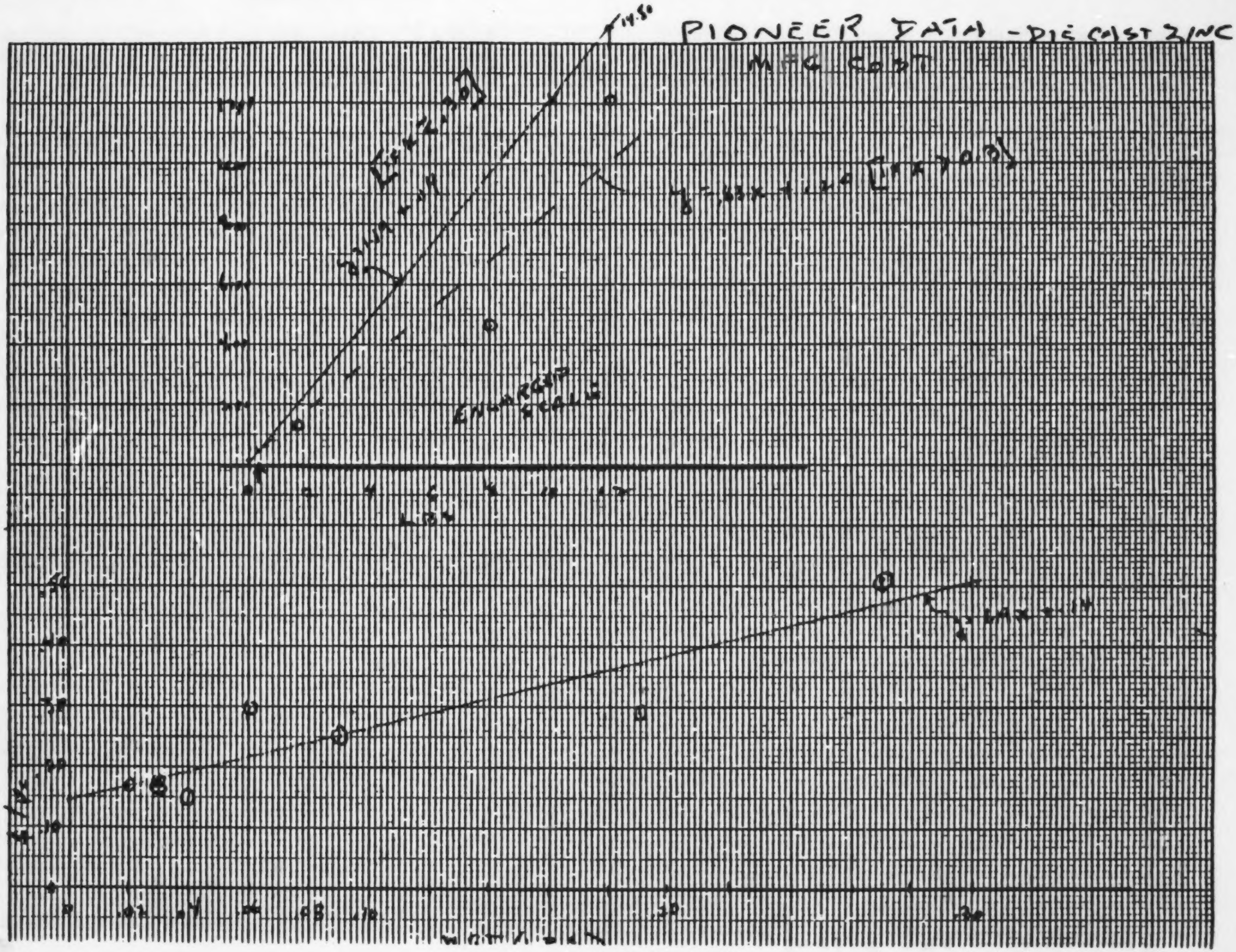


PIONEER DATA - PLASTIC

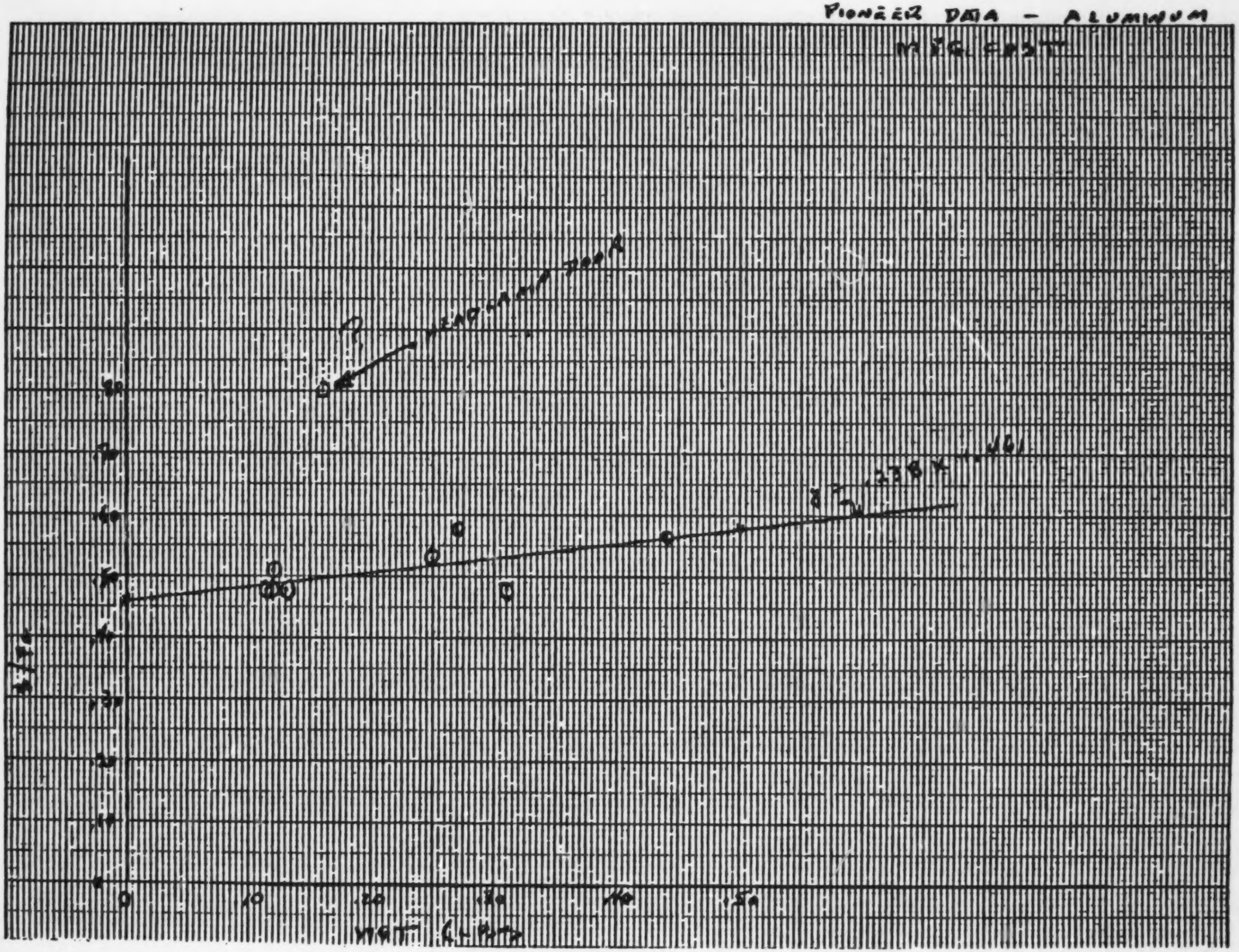


PIONEER DATA - DIE CAST ZINC

MFG COST



PIONEER DATA - ALUMINUM



ECONOMY OF SCALE EFFECT ON COSTS

To a large degree, this report is an extenion of an earlier one (EPA-460/2-78-002) which dealt with emission controls for automobiles rather than trucks. Some of the devices are identical for autos and trucks. Some are similar, but larger for trucks.

The size differential has been reflected in the unit cost estimations on a piece-by-piece basis, so that were size the only factor, the cost data herein would be a relatively straightforward extrapolation of the automobile estimates.

Another factor, however, intrudes: that of volume. Automobile manufacturing quantities are several times as great as truck quantities. This affects the manner in which a product is most economically manufactured, the larger quantities employing more automated equipment and less manual work plus some reduction in raw material costs. Overall, the unit cost is less for the high volume product.

Based on separate studies, the following learning curve type relationships have been developed and have been used in this report, where appropriate, to extend the automotive costs to cover trucks.

For Each Doubling of Capacity,
Multiply by:

	Investment	Cost/Unit
Equipment	1.45	0.73
Tooling	1.30	0.65
Labor	-	0.70
Material	-	0.90
TOTAL	-	0.80

DESCRIPTION OF USE OF THE FACTORS

Typical Annual Auto Capacity	350,000
Typical Annual Basic Truck Capacity	50,000

$$\text{Ratio} = \frac{350{,}000}{50{,}000} = 7$$

A multiple of 7 is equivalent to 2.81 doublings.

Derivation: $2^x = 7$

$$x \log 2 = \log 7$$

$$x = \frac{\log 7}{\log 2} = 2.81$$

$$2^{2.81} = 7$$

Example

Suppose the equipment investment to make 350,000 per year of a given part is \$10,000,000. Unit cost (12 year write-off) is therefore \$10,000,000 ÷ (12 x 350,000) = \$2.38.

Were this identical part to be made at a rate of only 50,000 per year, the resultant costs would be:

$$\text{Investment - }\$10{,}000{,}000 \div (1.45)^{2.81} = \$3{,}520{,}000$$

$$\text{Cost/Unit - }\$2.38 \div (.73)^{2.81} = \$5.76$$

INFLATION EFFECT ON COSTS

All costs shown in this report are quoted in 1977 dollars. This has been done to maintain continuity and consistency with the similar report, (EPA-460/3-78-002) made on automobiles in 1977.

In order to convert the quoted costs to any current year basis, some inflation rate must be selected, and the following equation used:

$$C = Q(1 + R)^N$$

Where,

C = Current Year Cost
Q = Cost Quoted in this Report
R = Selected Average Annual Inflation Rate
N = Number of Years since 1977

TABLE OF TYPICAL MULTIPLYING FACTORS $(1+R)^N$

		Average Inflation Rate (R)					
		2%	4%	6%	8%	10%	12%
Number of Years (N)	2-	1.04	1.08	1.12	1.17	1.21	1.25
	3-	1.06	1.12	1.19	1.26	1.33	1.40
	4-	1.08	1.17	1.26	1.36	1.46	1.57
	5-	1.10	1.22	1.34	1.47	1.61	1.76
	6-	1.13	1.27	1.42	1.59	1.77	1.97

DERIVATION OF THE ECONOMY OF SCALE, EFFECTS ON COST

Summary	For Each Doubling of Capacity, Multiply by these Factors	
	Investment	Cost/Unit
Equipment	1.45	0.73
Tooling	1.30	0.65
Labor	-	0.70
Materials	-	0.90
TOTAL	-	0.80

DATA RECAP

	5,000/YR	50,000/YR	150,000/YR
Equip. $/Unit	$156.99	$58.26	$34.59
Equip. Investment(12-Yr)	$9,419,400	$34,956,000	$62,262,000
Tooling $/Unit	$424.51	$82.74	$46.12
Tooling Investment(3-Yr)	$6,367,650	$12,411,000	$20,754,000
Labor $/Unit	$2,221.68	$1,110.48	$497.68
Material $/Unit	$1,927.23	$1,349.08	$1,156.33
Total $/Unit	$5,619.07	$3,044.75	$1,933.79

Qty. Ratios	Doublings (N)
$\frac{150,000}{5,000} = 30$	$2^n = 30$ $n = 4.91$
$\frac{50,000}{5,000} = 10$	$2^n = 10$ $n = 3.71$
$\frac{150,000}{50,000} = 3$	$2^n = 3$ $n = 1.58$

EQUIPMENT

Qty. Ratio	Invest. Ratio			Use
30	6.61	$F^{4.91} = 6.61$	F= 1.47	1.45
10	3.71	$F^{3.71} = 3.71$	F= 1.48	
3	1.78	$F^{1.58} = 1.78$	F= 1.44	

Unit Cost $\frac{1.45}{2} = .73$

TOOLING

Qty. Ratio	Invest. Ratio			
30	3.26	$F^{4.91} = 3.26$	F= 1.27	1.30
10	1.95	$F^{3.71} = 1.95$	F= 1.22	
3	1.67	$F^{1.58} = 1.67$	F= 1.38	

Unit Cost $\frac{1.30}{22} = .65$

LABOR

Qty. Ratio	Invest. Ratio			
30	.22	$F^{4.91} = .22$	F= .73	.70
10	.50	$F^{3.32} = .50$	F= .81	
3	.45	$F^{1.58} = .45$	F= .60	

MATERIAL

Qty. Ratio	$/Unit Ratio			Use
30	.60	$F^{4.91} = .60$	F= .90	.90
10	.70	$F^{3.32} = .70$	F= .91	
3	.86	$F^{1.58} = .86$	F= .91	

TOTAL

Qty. Ratio	$/Unit Ratio			
30	.35	$F^{4.91} = .35$	F= .81	.80
10	.54	$F^{3.32} = .54$	F= .83	
3	.64	$F^{1.58} = .64$	F= .75	

INTRODUCTORY SUMMARY TO COVER ITEMS 10-16

CATALYTIC CONVERTERS--GENERAL

There are seven types of catalytic converters to be considered.

Categorized by function, they fall into four classes: 3-way, oxidation, reduction, and start. Categorized by physical configuration, there are only two classes: in-line cylindrical and under-floor pan.

	Configuration Class	
Catalyst Function Class	In-Line Cylindrical	Under-Floor Pan
Monolithic 3-Way	X	
Monolithic Oxidation	X	
Monolithic Reduction		X
Monolithic Start	X	
Pelleted Oxidation		X
Pelleted Reduction		X
Metallic Reduction	X	

For purposes of cost estimating, the configuration classification is by far the more applicable, and has been used in the methodology underlying the sections following.

The first section, "Monolithic 3-Way Catalysts," presents in detailed fashion the step-by-step logic employed in the estimations. Subsequent sections refer to this logic where applicable, and expand only on pertinent details.

In each case, an equation is provided by which, when the catalytic content and the volume are specified, the estimated plant manufacturing cost and retail price equivalent can be calculated. These equations are embodied in forms A, B, and C.

CALCULATION OF THE COST PER GRAM OF CATALYTIC COMPOUNDS

Conversion Factors - Weight

The material prices are typically quoted in varying units of weight. Herewith is a list of factors by which to convert each to grams.

Avoirdupois pounds × 453.5924 = grams
Avoirdupois ounces × 28.3495 = grams
Troy pounds × 373.248 = grams
Troy ounces × 31.104 = grams

Conversion Factors - Volume

Cubic feet × 1728 = cubic inches
Square feet × 144 = square inches

Cost Per Gram of a Composition of Materials - (Exact Method)

To calculate the compound cost in dollars per gram, use the following format:

	Quoted Price		Conversion to $/Gram		Pro-Portion in	Compound
Material	$	Unit	Conv. Factor	$/Gram	Compound	$/Gram
A-1	B	C	D	E	F	H
A-2						
A-3						
Etc.						
Total Compound					G 1.000	J

A-1, A-2, Etc. - List ingredients
B & C - Quoted $ and units in which quoted
D - Appropriate conversion factor from 1.1
E - Divide B by D
F - List proportion as decimals (10% = 0.10)
G - Sum of column F must equal 1.000
H - Multiply F by E
J - Sum of column H equals compound cost per gram

Example 1

What is the cost per gram of a compound which contains 2% rhemium; 0.4% ruthenium; 3% nickel; and in which the platinum-to-rhodium ratio is 25:1?

Solution -

Rhenium = .020
Ruthenium = .004
Nickel = .030
Subtotal = .054

Remainder = 1.000-.054 = .946

$$\text{Platinum} \quad \frac{25}{25+1} \times .946 = .910$$

$$\text{Rhodium} \quad \frac{1}{25+1} \times .946 = .036$$

Total 1.000

Material	Quoted Price $	Quoted Price Unit	Conversion to $/Gram Factor	Conversion to $/Gram $/Gram	Pro-Portion	Compound $/Gram
Platinum	167.00	T. oz	31.104	5.369	.910	4.886
Rhodium	455.00	T. oz.	31.104	14.628	.036	.527
Rhenium	775.00	Av. lb.	453.5924	1.709	.020	.034
Nickel	2.23	Av. lb.	453.5924	.005	.030	-
Total Compound					1.000	5.447

Cost per Gram of a Composition of Substrate Materials - (Approximation Method)

This short-cut method, within the proportion limits proscribed, will deviate no more than 2% from the exact method described above.

Procedure

1. Calculate the cost per gram as if platinum and rhodium were the only ingredients (Pt + Rh = 100%).
2. Multiply this by the proportion represented by the sum of platinum and rhodium.
3. Add to this the product of the remaining proportion times $.67.

Example 2

What is the cost per gram of a compound which contains 2% rhenium; 0.4% ruthenium; 3% nickel; and in which the platinum-to-rhodium ratio is 25: 1?

1.	Platinum	25 parts	x $5.369	= $134.225
	Rhodium	1 part	x 14.628	= 14.628
	Totals	26 parts		$148.853

Cost/gram of mix $\frac{148.853}{26} = \$5.725$

2.	Platinum	91.0
	Rhodium	3.6%
	Sum	94.6%

.946 x $5.725 = $5.416

3. (1.000 - .946) x $.67 = $.036

4. $5.416 + $.036 = $5.452 (answer)

(Compare with $5.447gotten by Exact Method, Example 1, Section 1.3.2.)

Discussion - The short-cut method is made feasible because of two factors:

(a) Platinum and rhodium constitute 84.5% or more of the mixture, and

(b) The unit price of these is much greater than of the other constituents.

Typical Extreme Calculation

Platinum to Rhodium = 2: 1 (upper cost ratio)

Platinum & Rhodium = 84.5% (lower limit)
Rhenium = 5.0% (upper limit)
Ruthenium = 0.5% (upper limit)
Nickel = 10.0% (upper limit)
100.0%

Platinum	$5.369 x 2/3 x .845	=	$3.025
Rhodium	14.628 x 1/3 x .845	=	4.120
	Subtotal		$7.145
Rhenium	1.709 x .050	=	.085
Ruthenium	2.009 x .005	=	.010
Nickel	.005 x .100	=	.001
			$7.241

GRAMS OF COMPOUND REQUIRED FOR VARIOUS VOLUMES AND LOADINGS

		LOADING (Gm/Ft^3)									
		1	5	10	15	20	30	40	50	60	70
Volume (in^3)	1	.00058	.00289	.00579	.00868	.01157	.01736	.02315	.02894	.03472	.04051
	10	.00579	.029	.058	.087	.116	.174	.231	.289	.347	.405
	20	.01157	.058	.116	.174	.231	.347	.463	.579	.694	.810
	50	.02894	.145	.289	.434	.579	.868	1.16	1.45	1.74	2.03
	100	.05787	.289	.579	.868	1.16	1.74	2.31	2.89	3.47	4.05
	150	.08681	.434	.868	1.30	1.74	2.60	3.47	4.34	5.21	6.08
	200	.11574	.579	1.16	1.74	2.32	3.47	4.63	5.79	6.94	8.10
	250	.14468	.723	1.45	2.17	2.89	4.34	5.79	7.23	8.68	10.13
	300	.17361	.868	1.74	2.60	3.47	5.21	6.94	8.68	10.42	12.15
	350	.20255	1.01	2.03	3.04	4.05	6.08	8.10	10.13	12.15	14.18
	400	.23148	1.16	2.32	3.47	4.63	6.94	9.26	11.57	13.89	16.20

Grams required = Loading (gm/ft^3) x Volume (in^3) ÷ 1728

Note that the last three ingredients which represented 15.5% of the total weight added only $.096 to the subtotal cost of Platinum and Rhodium.

The short-cut formula substitutes 15.5% x $.67 = $.104 for the calculated $.096, creating an error of $.008, which is only 0.11% of the total.

CALCULATION OF THE WEIGHT OF CATALYTIC COMPOUND USED PER CONVERTER

Volume used is expressed in cubic inches.

Loading is spoken of in grams per cubic foot. For ease of calculation this is converted to grams per cubic inch.

$$1 \text{ gram/ft}^3 \times 1/1728 = .0005787 \text{ gm/in}^3$$

Total weight equals volume times loading.

$$\text{weight (grams)} = \text{volume (in}^3) \times \text{loading (gm/ft}^3) \div 1728$$

The matrix given in this section gives grams required for various combinations of volume and loading.

CALCULATION OF THE COST OF CATALYTIC COMPOUND PER CONVERTER

Cost per converter equals grams required (Section 2) times the cost per gram of the compound (Section 1).

For purposes of ready reference, the table on the following page is presented giving substrate compound costs at selected values of platinum-rhodium ratio, grams required, and total platinum-rhodium content.

Also in that table the following material prices are used:

Platinum	\$ 5.369/gm =	\$167/Troy oz.
Rhodium	14.628/gm =	455/Troy oz.
Rhenium	1.709/gm =	53/Troy oz.
Ruthenium	2.009/gm =	62/Troy oz.
Nickel	.005/gm =	2.23/av. lb.

Intermediate values may be interpolated, or calculated directly.

Equation for calculating cost of substrate material per converter.

$$\text{COST} = \left\{(Pp + Pr)\,\frac{167Pp + 455Pr}{31.103} + \left[1-(Pp + Pr)\right].67\right\}\left\{\frac{V\,L}{1728}\right\}$$

$$\text{when } \langle Pp + Pr \rangle \geq .845$$

where Pp = Percent Platinum ÷ 100
Pr = Percent Rhodium ÷ 100
V = Volume in cubic inches
L = Loading in grams per cubic foot

COST OF SUBSTRATE MATERIAL PER CONVERTER

% Platinum + % Rhodium = 100%
(See Note 3 if <100%)

Line	Total Grams Substrate Required (Note 1)	Ratio Platinum to Rhodium and Cost Per Gram (Note 2)							
		2:1 $ 8.455	5:1 $ 6.912	7:1 $ 6.526	9:1 $ 6.295	11:1 $ 6.141	19:1 $ 5.832	25:1 $ 5.725	30:1 $ 5.668
1	.029	$ .25	$ .20	$ .19	$ .18	$ .18	$ .17	$ .17	$ .16
2	.058	.49	.40	.38	.37	.36	.34	.33	.33
3	.116	.98	.80	.76	.73	.71	.68	.66	.66
4	.174	1.47	1.20	1.14	1.10	1.07	1.01	1.00	.99
5	.289	2.44	2.00	1.89	1.82	1.77	1.69	1.65	1.64
6	.579	4.90	4.00	3.78	3.64	3.56	3.38	3.31	3.28
7	1.16	9.81	8.02	7.57	7.30	7.12	6.77	6.64	6.57
8	1.74	14.71	12.03	11.36	10.95	10.69	10.15	9.96	9.86
9	2.31	19.53	15.97	15.08	14.54	14.19	13.47	13.22	13.09
10	3.47	29.34	23.98	22.65	21.84	21.31	20.24	19.87	19.67
11	4.05	34.24	27.99	26.43	25.49	24.87	23.62	23.19	22.96
12	5.21	44.05	36.01	34.00	32.80	31.99	30.38	29.83	29.53
13	6.08	51.41	42.02	39.68	38.27	37.34	35.46	34.81	34.46
14	6.94	58.60	47.97	45.29	43.69	42.62	40.47	39.73	39.34
15	7.23	61.13	49.97	47.18	45.51	44.40	42.17	41.39	40.98
16	8.10	68.49	55.99	52.86	50.99	49.74	47.24	46.37	45.91
17	9.26	78.29	64.01	60.43	58.29	56.87	54.00	53.01	52.49
18	10.13	85.65	70.02	66.11	63.77	62.21	59.08	57.99	57.42
19	11.57	97.82	79.97	75.51	72.83	71.05	67.48	66.24	65.58
20	12.15	102.73	83.98	79.29	76.48	74.61	70.86	69.56	68.87
21	13.89	117.44	96.01	90.65	87.44	85.30	81.01	79.52	78.73
22	14.18	119.89	98.01	92.54	89.26	87.08	82.07	81.18	80.37
23	16.20	136.97	111.97	105.72	101.98	99.48	94.48	92.75	91.82

Note 1: Determine grams required from the table or formula below it. Locate nearest line (or interpolate between two lines) and read $ in appropriate ratio column.

Note 2: Cost per gram calculated at Platinum $167/Troy oz. = $5.369/gram and Rhodium $455/Troy oz. = $14.628/gram.

Note 3: When Rhenium, Ruthenium of Nickel are also included in the compound, multiply the value from the table by the combined percentages of Platinum and Rhodium; add to this the remaining percentage times $.67 times total grams required.

DETERMINATION OF MONOLITHIC SUBSTRATE SHELL DIMENSIONS

Imposed Space Limits to Shell

Diameter Shell - 6.0"
Length Shell - 240"

Implied space limits to substrate

Diameter - 6.0 - 0.5 (metal mesh) = 5.5"
Length - 24.0 - 1.1 (endcap) = 22.9"

Two selected shell diameters to accommodate the range of substrate volumes: (refer to graph 4.3)

Vol (in)	Dia (in.)	Length (in.)
0-150	4.0	0-15.1
151-400	5.4	9.7-24.0

Length of shell required at given substrate volume.

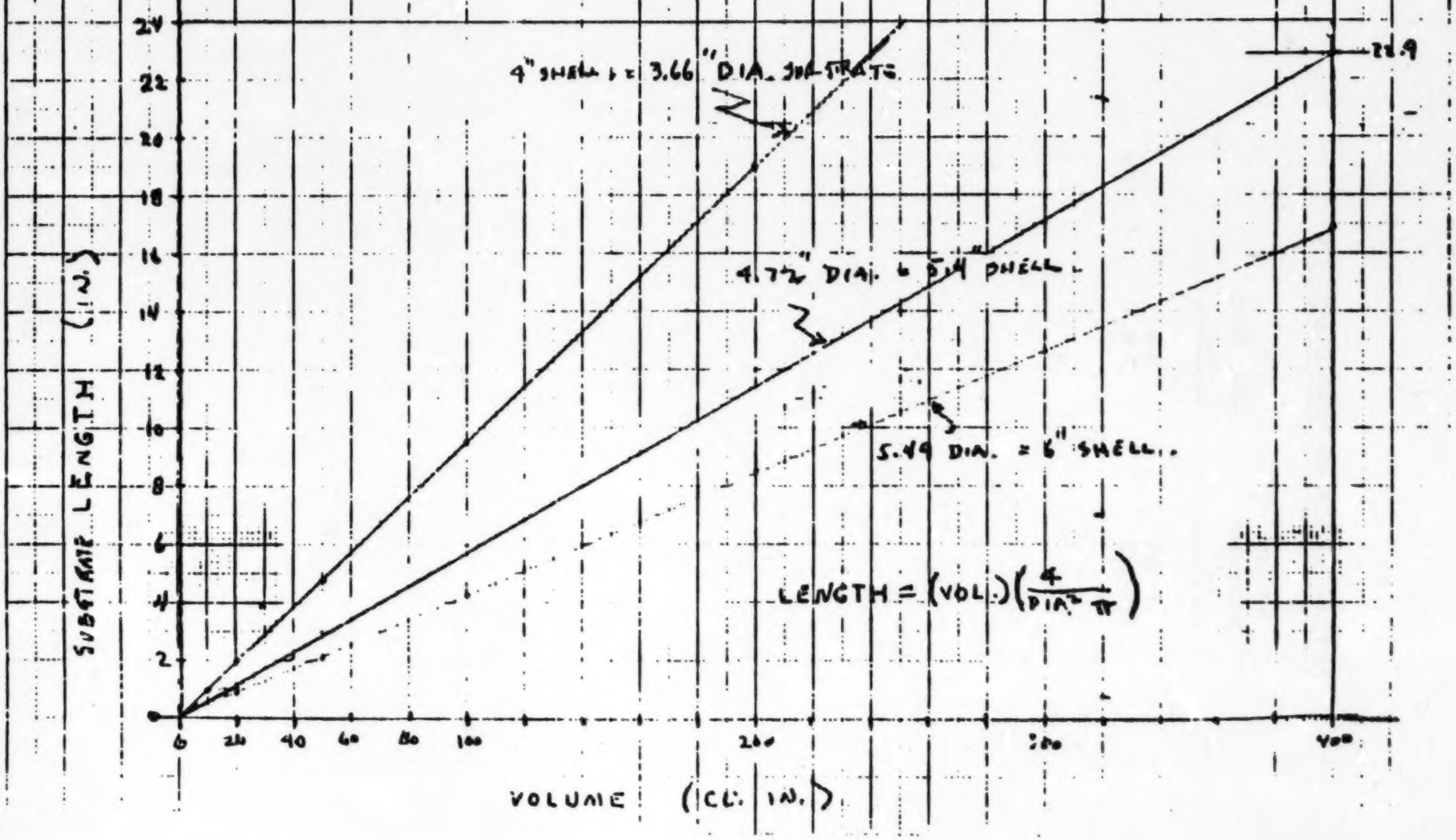
Substrate Volume (in)	Dia. Shell (incl. mesh)	Length Shell (incl. ca2)
1	4.0	.10+1.1= 1.1
10	4.0	.95+1.1= 2.1
20	4.0	1.90+1.1= 3.0
50	4.0	4.75+1.1= 5.9
100	4.0	9.50+1.1=10.6
150	4.0	14.26+1.1=15.4
151	5.4	8.63+1.1= 9.7
200	5.4	11.43+1.1=12.5
250	5.4	14.29+1.1=15.4
300	5.4	17.15+1.1=18.3
350	5.4	20.00+1.1=21.1
400	5.4	22.86+1.1=23.9

Ref: Pg 92

GRAPH 4.3

LENGTH OF SUBSTRATE REQUIRED TO ATTAIN VOLUME
AT THREE SPECIFIC DIAMETERS

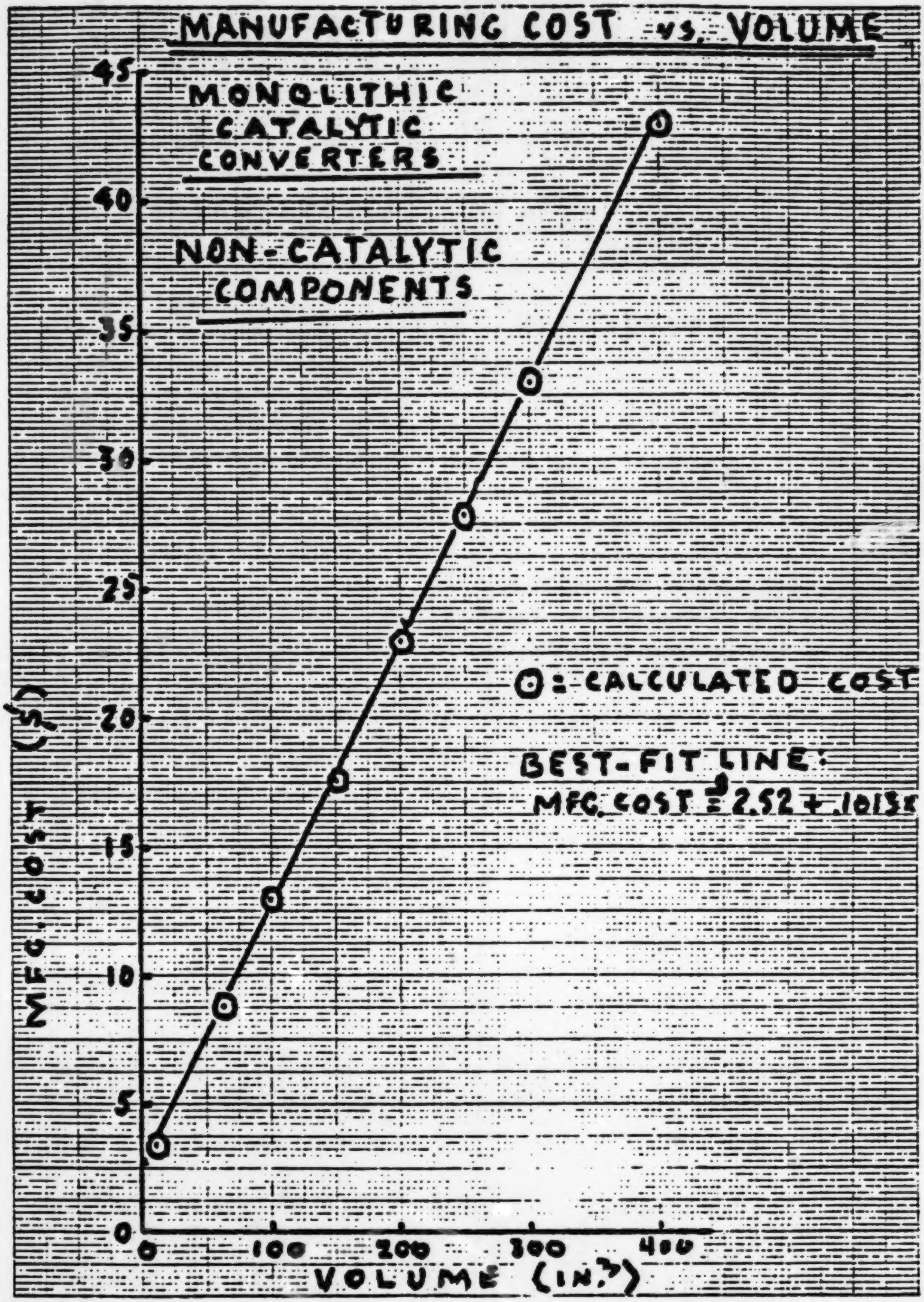
LIMITS: LENGTH 24" MAX. OVERALL SHELL ; LESS 1.1 = 22.9" MAX LENGTH OF SUBSTRATE
VOLUME 400 IN^3 MAX.



LENGTH = $(\text{VOL.})\left(\frac{4}{\text{DIA}^2\,\pi}\right)$

DETERMINATION OF RING DIAMETER

Volume Substrate In.	Dia. Ring In.
0-150	4.0
151-400	5.4



MANUFACTURING COST vs. VOLUME

MFG. COST CALCULATIONS - NONCATALYTIC COMPONENTS

		Vol. - 65 (Base) Dia. - 4 Lgth. - 7.2					Vol. - 10 Dia. - 4 Lgth. - 2.1				
Part	Mat'l	Weight	Mat'l Cost	Labor	OH	Mfg. Cost	Weight	Mat'l Cost	Labor	OH	Mfg. Cost
Cvtr. Assy.			-	.2500	.1000	.3500		-	.1884	.0754	.2638
Shell	409 SS	2.00	.80	.0625	.0250	.8875	.76	.30	.0393	.0157	.3550
Rings (No.)	409 SS	1.00	.40	.0312	.0125	.4437	.50	.20	.0156	.0062	.2218
In. Cone	409 SS	1.00	.40	.0312	.0125	.4437	1.00	.40	.0312	.0125	.4437
Out. Cone	409 SS	1.00	.40	.0312	.0125	.4437	1.00	.40	.0312	.0125	.4437
In. Pipe	409 SS	1.00	.40	.0312	.0125	.4437	1.00	.40	.0312	.0125	.4437
Flanges	409 SS	.25	.10	.0156	.0062	.1218	.25	.10	.0156	.0062	.1218
Mesh	409 SS	.15	.06	.0156	.0062	.0818	.04	.02	.0088	.0035	.0323
Hdwr.	Steel	.10	.02	.0156	.0062	.0418	.10	.02	.0156	.0062	.0418
Substrt.	Ceramic	1.30	4.68	.1250	.0500	4.8550	.21	.76	.0618	.0247	.8465
Wash Coat	Al_2O_3	-	.60	.0625	.0250	.6875		.10	.0309	.0124	.1433
	TOTALS		7.86	.6716	.2686	8.8002		2.70	.4696	.1878	3.3574

		Vol. - 100 Dia. - 4 Lgth. - 10.6					Vol. - 150 Dia. - 4 Lgth. - 15.4				
Cvtr. Assy.		9.46	-	.2857	.1143	.4000	12.27	-	.3445	.1378	.4823
Shell	409 SS	2.83	1.13	.0781	.0312	1.2393	4.00	1.60	.1000	.0400	1.7400
Rings (No.)	409 SS	1.00	.40	.0312	.0125	.4437	1.50	.60	.0468	.0187	.6655
In. Cone	409 SS	1.00	.40	.0312	.0125	.4437	1.00	.40	.0312	.0215	.4437
Out. Cone	409 SS	1.00	.40	.0312	.0125	.4437	1.00	.40	.0312	.0125	.4437
In. Pipe	409 SS	1.00	.40	.0312	.0125	.4437	1.00	.40	.0312	.0125	.4437
Flanges	409 SS	.25	.10	.0156	.0062	.1218	.25	.10	.0156	.0062	.1218
Mesh	409 SS	.22	.09	.0200	.0080	.1180	.32	.13	.0262	.0105	.1667
Hdwr.	Steel	.10	.02	.0156	.0062	.0418	.10	.02	.0156	.0062	.0418
Substrt.	Ceramic	2.06	7.42	.1684	.0674	7.6558	3.10	11.16	.2284	.0914	14.4798
Wash Coat	Al_2O_3		.95	.0842	.0337	1.0679		1.43	.1142	.0457	1.5899
	TOTALS		11.31	.7924	.3170	12.919		16.24	.9849	.3940	17.6189

MFG. COST CALCULATIONS - NONCATALYTIC COMPONENTS

		Vol. - 200 Dia. - 5.4 Lgth. - 12.5					Vol. - 250 Dia. - 5.4 Lgth. - 15.4				
Part	Mat'l	Weight	Mat'l Cost	Labor	OH	Mfg. Cost	Weight	Mat'l Cost	Labor	OH	Mfg. Cost
Cvtr. Assy.		15.60	-	.4125	.1650	.5775	17.67	-	.4580	.1832	.6412
Shell	409 SS	4.56	1.82	.1105	.0442	1.9747	5.52	2.21	.1285	.0514	2.3899
Rings (No.)	409 SS	2.03	.81	.0567	.0227	.8894	2.03	.81	.0567	.0227	.8894
In. Cone	409 SS	1.35	.54	.0378	.0151	.5929	1.35	.54	.0378	.0151	.5929
Out. Cone	409 SS	1.35	.54	.0378	.0151	.5929	1.35	.54	.0378	.0151	.5929
In. Pipe	409 SS	1.35	.54	.0378	.0151	.5929	1.35	.54	.0378	.0151	.5929
Flanges	409 SS	.34	.14	.0190	.0076	.1666	.34	.14	.0190	.0076	.1666
Mesh	409 SS	.35	.14	.0281	.0112	.1793	.43	.17	.0331	.0132	.2163
Hdwr.	Steel	.14	.03	.0193	.0078	.0571	.14	.03	.0193	.0078	.0571
Substrt.	Ceramic	4.13	14.87	.2880	.1152	15.2732	5.16	18.38	.3476	.1391	19.0667
Wash Coat	Al_2O_3		1.90	.1440	.0576	2.1016	-	2.38	.1738	.0695	2.6233
	TOTALS		21.33	1.1915	.4766	22.9981		25.94	1.3494	.5398	27.8292

		Vol. - 300 Dia. - 5.4 Lgth. - 18.3					Vol. - 400 Dia. - 5.4 Lgth. - 23.9				
Part	Mat'l	Weight	Mat'l Cost	Labor	OH	Mfg. Cost	Weight	Mat'l Cost	Labor	OH	Mfg. Cost
Cvtr. Assy.		20.40	-	.5153	.2061	.7214	25.14	-	.6175	.2470	.8645
Shell	409 SS	6.47	2.59	.1463	.0585	2.7948	8.31	3.32	.1808	.0723	3.5731
Rings (No.)	409 SS	2.70	1.08	.0756	.0302	1.1858	3.38	1.35	.0945	.0378	1.4823
In. Cone	409 SS	1.35	.54	.0378	.0151	.5929	1.35	.54	.0378	.0151	.5929
Out. Cone	409 SS	1.35	.54	.0378	.0151	.5929	1.35	.54	.0378	.0151	.5929
In. Pipe	409 SS	1.35	.54	.0378	.0151	.5929	1.35	.54	.0378	.0151	.5929
Flanges	409 SS	.34	.14	.0190	.0076	.1666	.34	.14	.0190	.0076	.1666
Mesh	409 SS	.51	.20	.0381	.0152	.2533	.67	.27	.0480	.0192	.3372
Hdwr.	Steel	.14	.03	.0193	.0078	.0571	.14	.03	.0193	.0078	.0571
Substrt.	Ceramic	6.19		.4072	.1629	22.8501	8.25		.5261	.2104	30.4365
Wash Coat	Al_2O_3	-	2.86	.2036	.0814	3.1450	-	3.81	.2630	.1052	4.1782
	TOTALS		30.80	1.5378	.6150	32.9528		40.24	1.8816	.7526	42.8742

Noble Metal Prices

	Price per Troy Ounce*	
Metal	**Wholesale**	**Retail**
Platinum	$162	$172
Iridium	300	310
Rhodium	400	410
Paladium	60	65
Ruthenium	60	65

---

*Troy Ounce = 31.1035 grams

Source: Matthey-Bishop, Inc.

EVOLUTION OF DISTRIBUTION AND ECONOMICS

AUTOMOTIVE AFTERMARKET

ERAS: 1912-1928
1925-1940
1940-1950
1950-1960
1960-1977

TO INCLUDE:

- THE METHODOLOGY
- THE ECONOMICS
- THE CONFLICTS
- THE OUTGROWTHS

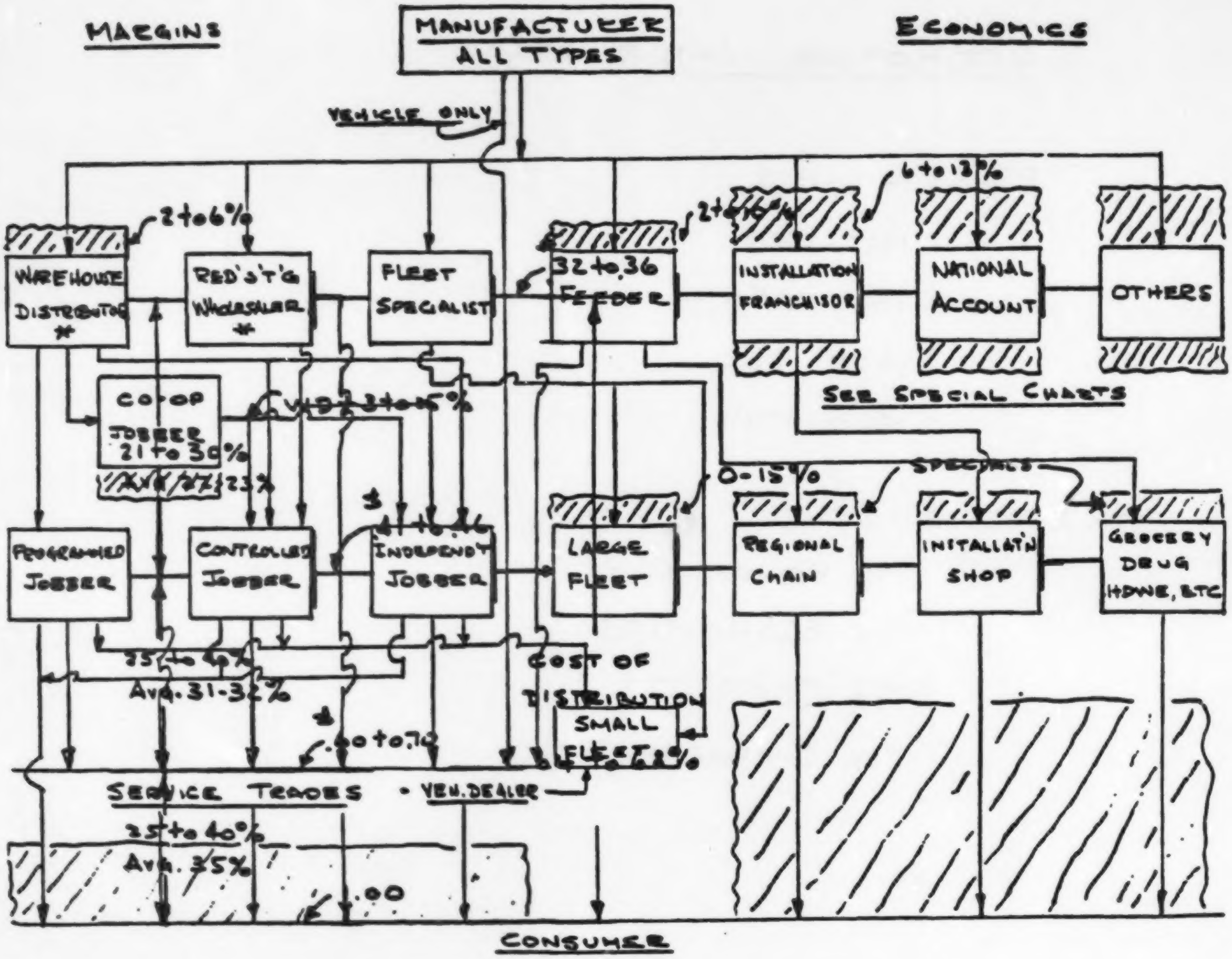
AN ADDRESS BY: J.M. YANTIS, CHAIRMAN
MID-AMERICA INDUSTRIES, INC.

BEFORE: DISTRIBUTORS INSTITUTE
DRAKE HOTEL
Chicago
MARCH 11, 1977

SLIDE 1

ERA 1960-1977

THE MATURING YEARS


MARGINS
MANUFACTURER ALL TYPES
ECONOMICS
VEHICLE ONLY
2 to 6%
WAREHOUSE DISTRIBUTOR *
RED'S'T'G WHOLESALER *
FLEET SPECIALIST
32 to 36
FEEDER
2 to 15%
6 to 12%
INSTALLATION FRANCHISOR
NATIONAL ACCOUNT
OTHERS
SEE SPECIAL CHARTS
CO-OP JOBBER
21 to 30%
AVG 27
23%
3 to 25%
$
0-15%
SPECIALS
PROGRAMMED JOBBER
CONTROLLED JOBBER
INDEPEND'T JOBBER
LARGE FLEET
REGIONAL CHAIN
INSTALLAT'N SHOP
GROCERY DRUG HDWE, ETC
35 to 40%
Avg. 31-32%
COST OF DISTRIBUTION
$
.60 to .70
SMALL FLEET
SERVICE TRADES
VEH. DEALER
35 to 40%
Avg. 35%
1.00
CONSUMER

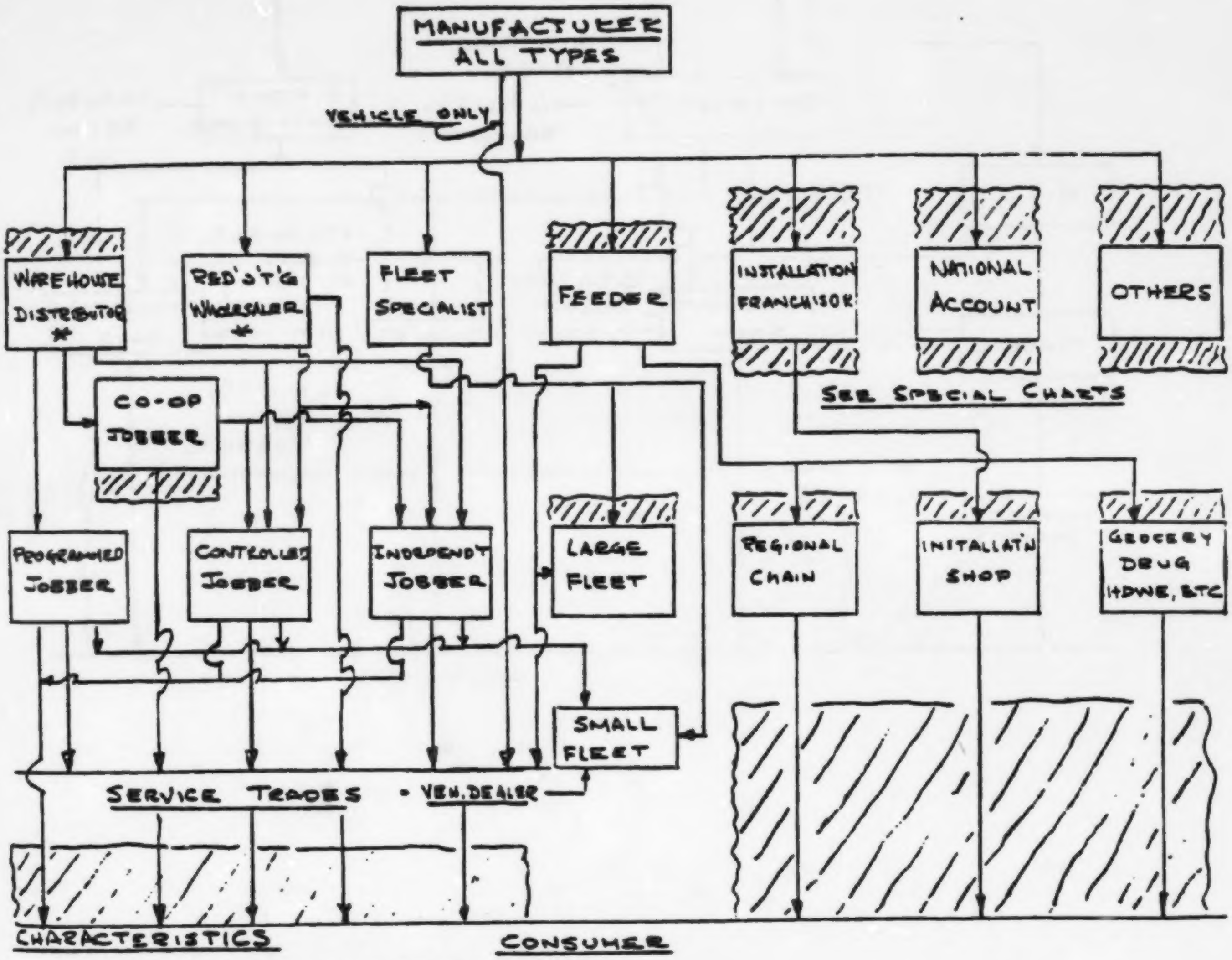
SLIDE 6
PART 2

SLIDE 6
PART 1

* ALSO ATTEMPTS TO SELL LARGE FLEETS AND INSTALLATION SHOPS.

ERA 1960-1977

THE MATURING YEARS


MANUFACTURER
ALL TYPES
VEHICLE ONLY
WAREHOUSE DISTRIBUTOR *
RED'S'T'G WHOLESALER *
FLEET SPECIALIST
FEEDER
INSTALLATION FRANCHISOR
NATIONAL ACCOUNT
OTHERS
SEE SPECIAL CHARTS
CO-OP JOBBER
PROGRAMMED JOBBER
CONTROLLED JOBBER
INDEPEND'T JOBBER
LARGE FLEET
REGIONAL CHAIN
INSTALLAT'N SHOP
GROCERY DRUG HDWE, ETC
SMALL FLEET
SERVICE TRADES
• VEH. DEALER
CONSUMER

CHARACTERISTICS

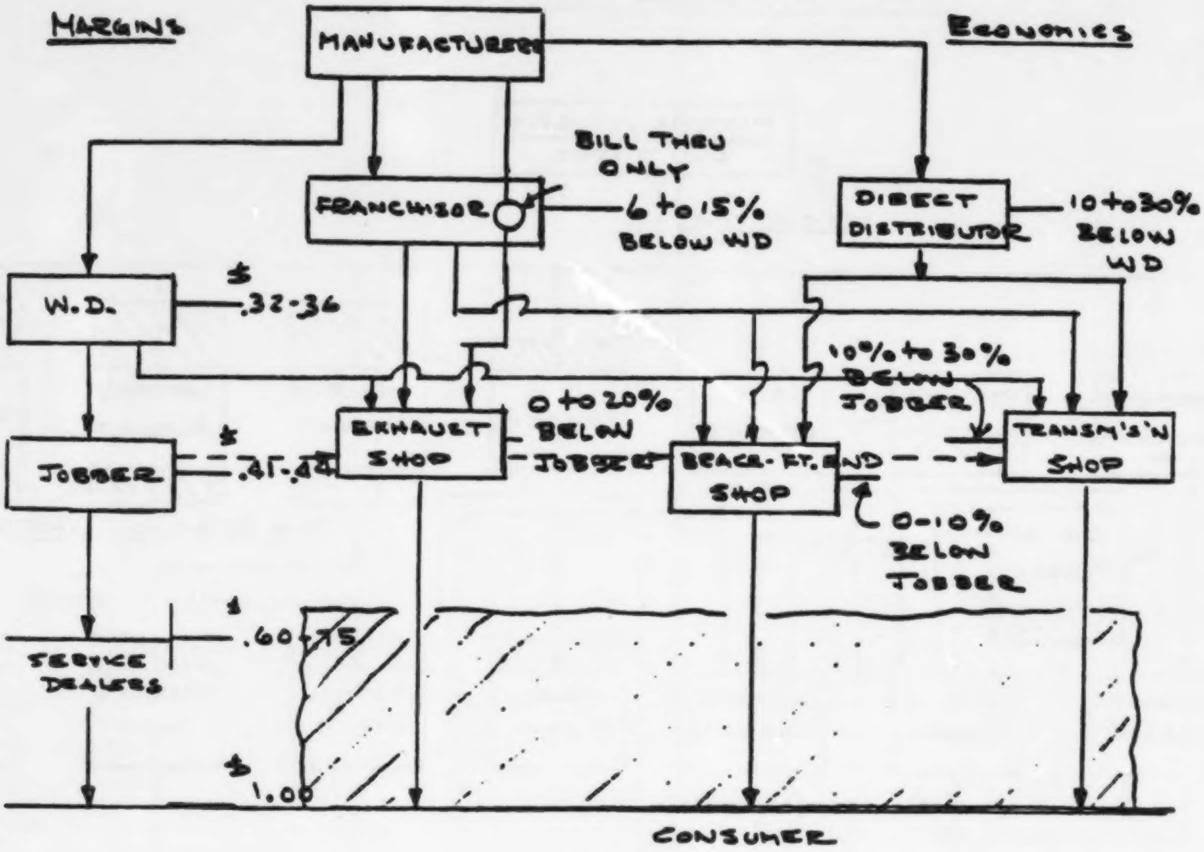
1. ADDED CHANNELS OF DISTRIBUTION.
2. NEW FLEXIBILITIES IN PRICING.
3. NEW PRICING PHENOMENON BASED ON 'COST-JUSTIFICATION' - 'MEETING COMPETITION' - 'PRIVATE BRANDING' - 'BIDDING'.
4. ELIMINATION OF REPORTING FOR FUNCTIONAL COMMISSION.
5. MANUFACTURERS LOSS OF CONTROL OF DISTRIBUTION.
6. OPENING OF WIDE MARGIN BETWEEN MANUFACTURERS RECOMMENDED CONSUMER PRICE & MANY RETAILERS COST.
7. ENTER 'SELF-INSTALLER' - ADVERTISING - STORE MODERNIZATION - JOBBERS RENDERING RETAIL SERVICE, ETC.

SLIDE 6
PART 3

SLIDE 6
PART 1

* ALSO ATTEMPTS TO SELL LARGE FLEETS AND INSTALLATION SHOPS.

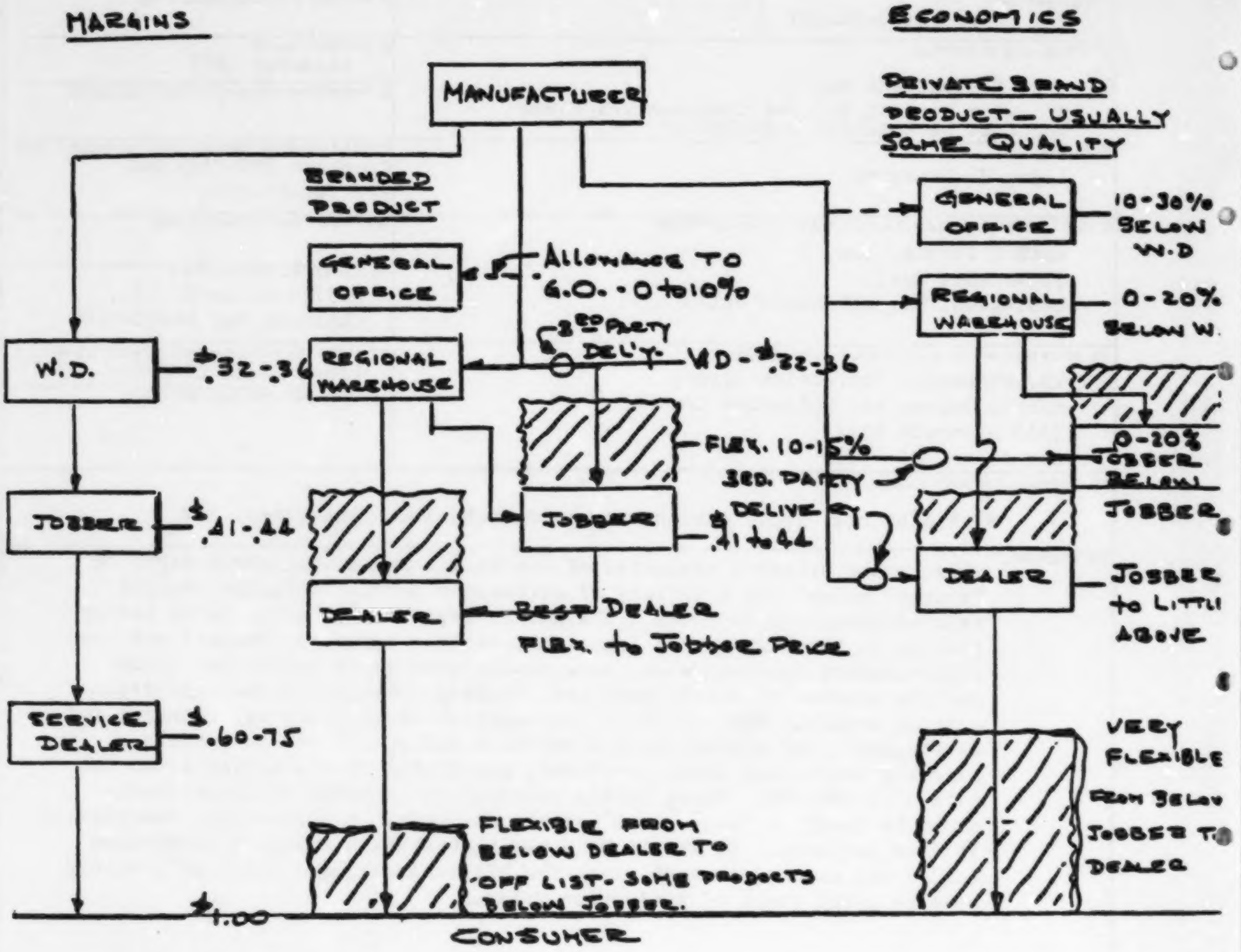
THE INSTALLATION SHOPS


MARGINS
MANUFACTURERS
ECONOMICS
BILL THRU ONLY
FRANCHISOR
6 to 15% BELOW WD
DIRECT DISTRIBUTOR
10 to 30% BELOW WD
W.D.
$ .32-.36
10% to 30% BELOW JOBBER
0 to 20% BELOW JOBBER
EXHAUST SHOP
JOBBER
$ .41-.44
BRAKE-FT. END SHOP
TRANSM'S'N SHOP
0-10% BELOW JOBBER
SERVICE DEALERS
$ .60-.75
$ 1.00
CONSUMER

SLIDE 7 PART 2

SLIDE 7 PART 1

THE NATIONAL ACCOUNTS



MARGINS
ECONOMICS
MANUFACTURER
BRANDED PRODUCT
PRIVATE BRAND PRODUCT — USUALLY SAME QUALITY
GENERAL OFFICE
Allowance to G.O. - 0 to 10%
W.D.
$.32-.36
REGIONAL WAREHOUSE
3RD PARTY DEL'Y.
WD - $.32-.36
FLEX. 10-15%
3RD. PARTY DELIVERY
JOBBER
$.41-.44
JOBBER
$.41 to .44
DEALER
BEST DEALER FLEX. to Jobber Price
SERVICE DEALER
$.60-.75
FLEXIBLE FROM BELOW DEALER TO OFF LIST - SOME PRODUCTS BELOW JOBBER.
$1.00
CONSUMER
GENERAL OFFICE
10-30% BELOW W.D
REGIONAL WAREHOUSE
0-20% BELOW W.
0-20% JOBBER BELOW JOBBER
DEALER
JOBBER to LITTLE ABOVE
VERY FLEXIBLE FROM BELOW JOBBER TO DEALER

SLIDE 8 PART 2

SLIDE 8 PART 1